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OPERATIONAL PERFORMANCE OF MESOSCALE AND LAM MODELS IN PREDICTION OF STRATOCUMULUS

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31st August 1993

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ABSTRACT

The operational trial of the new mesoscale model (NMM) showed the benefits of increased vertical resolution in the prediction of stratocumulus. It also showed that the NMM could produce good forecasts of stratocumulus which are improved further with the inclusion of MOPS humidity profiles derived with the benefit of human intervention to correct deficiencies in the current objective scheme. It was also found in one case that there was even greater impact from the MOPS data if sonde humidity data was excluded. The forecast was also sensitive to the physical parametrisations and more stratocumulus was produced when the boundary layer scheme included a parametrisation for non-local mixing.

Investigation of the operational performance of the mesoscale and LAM models during the period 5-10 March 1993 confirmed the forecasters' view that the NMM is unreliable in its prediction of stratocumulus. On occasion the models achieved remarkable accuracy; however the analyses and subsequent forecasts were also frequently deficient in cloud over land despite the inclusion of MOPS data in the NMM. It was found that if MOPS data had been produced the analyses and short forecasts were greatly improved if sonde humidity data was excluded. It was also found that when MOPS data was excluded the analyses and short forecasts were improved by modifications to the physical parametrisations, in particular by reducing the critical relative humidity in the cloud scheme.

Various conclusions are drawn and recommendations made for further investigations and improvements in the analysis and prediction of stratocumulus. In particular it is felt that there are currently inconsistencies between the relative humidity observations, their pre-processing and use in the data assimilation scheme and the model cloud scheme. The accuracy of the radio-sonde relative humidity data and the pre-processing scheme should be investigated before any attempt is made to alter the cloud parametrisation in the model. However since the model is currently deficient in low cloud it is recommended that the mesoscale convection parameters should be altered to be the same as those used for the climate and limited area models as this results in greater low cloud cover in various cases investigated so far.

1. Introduction

The LAM version of the unified model (Cullen 1991 and 1993) was introduced operationally in June 1991 and the mesoscale version in Dec 1992 (Ballard et al 1993). However there has been no systematic verification of the performance of these models in predicting low cloud. As part of the preparation of a paper for the ECMWF/GCSS workshop on 'Parametrisation of the cloud topped boundary layer' a quick investigation was undertaken and is reported here.

In section 2 the findings from the mesoscale pre-operational stratocumulus case are reviewed including sensitivities to assimilation and physical parametrisations. In section 3 the operational performance for a period of stratocumulus in March 1993 is investigated and in Section 4 the comments from the forecasters performing the intervention on the mesoscale cloud analysis during this period are reviewed. In section 5 the impact of MOPS and radiosonde humidity data in the analyses and forecasts is investigated. One forecast from this period is investigated in more detail in section 6. The preliminary conclusions from these investigations are discussed in section 7 and recommendations for further actions are made in section 8.

2. Mesoscale Operational Trial Case Study - 4/12/91

Only one stratocumulus case was included in the pre-operational trial of the new mesoscale model (NMM), Ballard et al 1993. This was from a period of stratocumulus lasting from about 2-6 December 1991. The old mesoscale model (Golding 1990) operational at that time performed poorly (Ballard 1991). Despite apparently good definitions of the cloud in the initial conditions, as a result of the IMI(Interactive Mesoscale Initialisation,Wright and Golding 1990), most of the stratocumulus was lost during the first three hours of the forecast and never completely regained.

2.1 1st Pre-operational Trial - UM version 2.4

In the first trial of the new model the basic unified model system was used for the new model, ie assimilation and model were basically as in the LAM , operational version in spring 92, with only radiosonde data being used to define humidities and no extra cloud data. The only major differences were in resolution (eg 17km and 11 boundary layer levels in the NMM and 50km and 5 boundary layer levels in the LAM , see figure 1) and the frequency of calls to the radiation scheme - 1/4hrly in the NMM and 3 hourly in the LAM. A set of experiments were run and compared with the operational mesoscale (OMM) and LAM forecasts. These were :

NMMAC: NMM with 6 hour data assimilation from 18Z 3/12/91 using 18Z LAM analysis and boundary conditions from the 0Z LAM assimilation and forecast.

NMMLAM: NMM with no assimilation starting from 0Z LAM analysis and using 0Z LAM boundary conditions.

OMMLAM: OMM starting from 0Z LAM analysis and no IMI using 0Z LAM boundary conditions.

All but the operational OMM were deficient in cloud over land at the start of the forecast, see figure 2. However there was benefit from the assimilation of radiosonde data at high resolution as can be seen from figure 3 where the NMMAC has the best definition of the cloud top and the dry air above the inversion at T+0 and this is not produced in a high resolution forecast run from a coarse resolution analysis as can be seen by the comparison of the T+6 NMMAC and NMM ascents. The NMMAC T+0 also has a larger areal cloud coverage than the LAM.

By T+15, see figure 4, all but the LAM and operational OMM have reasonable representations of the cloud coverage. The OMMLAM is a much better forecast than the operational one and possibly the best of the set. This shows that the poor stratocumulus prediction from the OMM was not a model problem but an initialisation problem. The loss of cloud from the operational model was a result of imbalances in the initial conditions. This shows that given reasonable balanced initial conditions the OMM had adequate parametrisations to forecast the stratocumulus on this occasion. Also despite the deficit in cloud at T+0 the initial conditions must have been reasonably good to produce such satisfactory forecasts. The NMMAC has more cloud than the NMM and both forecasts have less cloud over the sea than the OMMLAM. The LAM has erroneously produced fog (ie cloud in level 1) in the gap in cloud over Northern England and Scotland. This is absent in the NMM forecast possibly showing a benefit from the extra vertical resolution. However, various later runs of the NMM have also produced fog in the cloud free area so it may be very sensitive to the near surface conditions.

2.2 Sensitivity Studies with Operational Version of NMM (UM version 2.7)

For the operational version of the NMM the assimilation system was extended, Macpherson et al 1993, to include screen temperature and 10m wind data over land and relative humidity profiles derived from the MOPS (Moisture Observation Pre-processing System, Wright 1993). The model was also updated to use orography derived from a higher resolution source dataset, a roughness scheme including the effects of sub-gridscale orography, a convection scheme including the effects of downdraughts, an extension to the boundary layer scheme to include non-local mixing, an extension to the radiation scheme to allow for the change in solar zenith angle every timestep with a reduction in the frequency of calls from 1/4hrly to hourly and a change to the evaporation of large scale precipitation to be consistent with the new convection scheme.

2.2.1 Assimilation

The impact of the MOPS derived humidity data on the 3 hour forecasts is shown in figure 5 taken from Macpherson et al 1993. It can be seen that the deficiency in cloud cover over Ireland, Wales and Northern England is greatly improved by the inclusion of the MOPS data derived with the benefit of human intervention but there is very little impact when it is produced automatically. This is due to inadequacies in the current scheme for automatically calculating cloud cover and top from Meteosat infrared imagery of low, inversion capped clouds. The automatic scheme will frequently not detect the presence of low cloud over the sea and will set the cloud cover to zero in

those regions. Then any cloud correctly present in the model first guess will be removed. In the presence of an inversion that is inadequately resolved by the model, which is generally the case, the automatic scheme will also set the top of inversion capped clouds too high. These inadequacies can be relatively easily corrected by forecaster intervention.

Macpherson et al 1993 also showed that in the absence of MOPS data there had been a positive benefit from the assimilation of sonde humidity data in this case, as there was even less cloud in the analyses and forecasts with both MOPS and sonde humidity data removed than ones with only the MOPS data removed. However there was even greater impact from the MOPS data when that was included without the presence of sonde humidities, see figure 6.

2.2.2 Physical Parametrisations

2.2.2.1 Impact of non-local mixing scheme

The amount of cloud forecast in this case is also sensitive to the physical parametrisations used in the model. Figure 7 shows the predicted low and convective cloud cover at 15Z for various versions of the model run with assimilation including the same data in each case. Forecasts without the changes to the boundary layer, convection, evaporation and roughness schemes are very similar to those from the first trial. When the non-local mixing scheme is included more low cloud and less convective cloud is forecast. The low cloud coverage is then much more like the OMMLAM forecast from the 1st pre-operational trial. When the convection, evaporation and roughness changes are also included the forecast is then much more like the original forecast. There is slightly more low cloud, a residual impact from the non-local mixing scheme, but there is also more convective cloud which is probably due to the change to the convection scheme. The version of the convection scheme used in the NMM has larger values of parameters defining the initial mass flux and bouyancy excess than those used in the LAM which means that the convection is more vigorous and likely to trigger. In this case the convection is only shallow and contributing to the boundary layer mixing at the expense of the boundary layer scheme and hence production of stratified cloud. Convective cloud amounts are at most a few oktas compared with largely full cover low cloud amounts. When the parameters are reduced to the values used in the LAM and climate models the forecast cloud is then much more like that produced when only the non-local mixing scheme is included.

2.2.2.2 Impact of additional changes to the cloud scheme and horizontal diffusion (UM version 3.1)

Additional modifications to the unified model prognostic cloud and precipitation scheme have been included in the climate model but not yet in the new operational mesoscale model. The shape of the probability distribution function for the subgridscale fluctuations of saturation was changed from triangular to a top-hat and the scheme was formulated in terms of temperature T rather than the prognostic variable, liquid/ice water temperature TL so that the expression for the width of the distribution is now in

terms of the saturation humidity mixing ratio at temperature T rather than TL. The threshold for efficient rainfall production was reduced over sea points and the scheme for ice fallout was correctly formulated implicitly. These have also been tested on the 4/12/91 case in addition to the changes mentioned above, reduction of the convection parameters to the LAM and climate values, corrections to the surface exchanges to correctly account for different roughness lengths for heat and momentum, improvement to the implicit boundary layer scheme, a new scheme to calculate the screen temperature and 10m wind, a change of the horizontal diffusion scheme to 4th order from 2nd order using version 3.1 of the unified model. The 15 hour forecast cloud cover is shown in figure 8. The areal coverage of low cloud is similar to results with only the change to the non-local mixing scheme or the operational changes with the climate parameters. There is now cloud in the gap over northern England, this reaches the surface as fog but fog in this area was also produced in the operational version at 3.0 due to an unexplained difference from version 2.7. The low cloud cover over Ireland and the Atlantic is now reduced below full cover, although as a result of the random overlap assumption in the radiation scheme the total cover is still full. There is now even less convective cloud than with just the non-local mixing scheme.

3. Operational Performance 5-10 March 1993

We saw from section 2 that the operational version of the new mesoscale model can produce good forecasts of stratocumulus cloud cover which can be further improved by the inclusion of humidity data from the MOPS given careful human intervention in a non operational environment. So how does the model perform in fully operational conditions when more cases can be investigated and there is limited time available for the forecaster to perform the intervention? The period 5-10 March 1993 was chosen for investigation from the CFO (Central Forecast Office) subjective verification, see Appendix A. These comments indicated that the forecasters were generally happy with the model's skill in startocumulus prediction in the forecasts 6Z 5/3/93, 6Z 7/3/93 and 0Z 8/3/93 but the model performed badly in the other runs. The marking scheme consists of overall scores for all aspects of the forecast of A,B or C where A is useful and C is misleading.

3.1 Synoptic Situation and observed cloud cover

During this period an anticyclone moved eastwards across the country with associated stratocumulus cloud cover, see figures 9 and 10. On the 5th a weak warm front with associated sleet and drizzle moved slowly south during the first half of the day and by the 9th the cloud had receded northwards ahead of a low pressure system with associated frontal system to the southwest of Ireland. Most of the country was cloud covered on the 5th. On the morning of the 6th there was stratocumulus and stratus (with bases 1000 to 3500 ft) reported over most of the British Isles. An area covering eastern and central parts of northern England and Scotland and extending out over the coastal waters of the North Sea was free of low cloud but there was overlying cirrus. On the morning of the 7th the only breaks in the low cloud were in the north east of Scotland and north west Ireland with bases 1500-3000 ft over low lying parts

of England and Ireland. On the morning of the 8th the low cloud was beginning to retreat northwestwards and had mainly cleared by the morning of the 9th leaving clear skies over most of England, Wales and southern Scotland.

3.2 Objective Verification of Cloud Cover

Figure 11 shows the mean error in the total cloud cover forecast by the mesoscale model for the surface observing stations in the UK area at three hourly intervals for all the forecasts covering this period. Biases are plotted for T+0 to T+18 for the 0Z forecasts and T+0 to T+30 for the 06Z forecasts. It can be seen that at the start of the period both the 0Z and 6Z forecasts on the 5th had low and consistent errors. However the analyses and forecasts degrade markedly on the 6th through to 0Z on the 7th before gradually improving again. Obviously the low biases on the 9th and 10th are less meaningful as there was very little cloud over the British Isles but at least it indicates that the model was not excessively overpredicting cloud. It can be seen that during the period 6th to 7th March the longer range forecasts are more accurate than the short range forecasts and analyses. This indicates that we cannot yet contemplate verifying model predicted cloud cover against the model analyses. There is an apparent marked improvement in forecast skill in the 6Z 6/3/93 forecast after T+12 and this will be explained later. It is reassuring to note that the objective errors correlate reasonably well with the CFO forecasters subjective verification of the forecast skill apart from the markings for the 0Z and 6Z 5/3/93 forecasts where they were marked down subjectively as a result of poor precipitation forecasts in the 6Z and maybe too harshly for the cloud in the 0Z considering the gross cloud cover errors in the later forecasts.

3.3 Comparison of analyses and forecasts for 6Z 6/3/93, 7/3/93 and 8/3/93

The forecast and analysed cloud covers verifying at 6Z 6/3/93, 6Z 7/3/93 and 6Z 8/3/93 have been studied in more detail, see figures 12 to 14.

From figure 12 it can be seen that the T+24 forecast from 5Z 6/3/93 is excellent (at least in terms of cover, bases have not been investigated), it even had the cirrus shield above the gap in the low cloud. However the T+6 forecast from 0Z 6/3/93 is greatly deficient in low cloud over central England, Wales and southern Ireland and the 6Z 6/3/93 analysis is even worse with most of the British Isles being cloud free. The equivalent LAM forecasts and analyses are also deficient in cloud.

From figure 13 the reason for the apparent increase in skill in the 6Z 6/3/93 forecast after T+12 can be seen - the T+24 forecast has fog covering most of England and Wales in an erroneous cloud free area throughout most of England, Wales and Scotland. The forecast has never recovered from the lack of cloud in the analysis, skies remained clear and fog was produced during the period of nocturnal cooling. Unfortunately no scheme has yet been developed to remove fog (which once developed may extend over more than one level above the surface) from the calculated forecast cloud cover. The T+6 forecast from 0Z 7/3/93 is also poor but at least no fog has developed and the forecast is better than the equivalent LAM forecast. The 6Z 7/3/93 analysis is still slightly

deficient in low cloud but much better than the forecasts verifying at that time and the equivalent LAM analysis.

It can be seen from figure 14 that the T+24 forecast cloud cover resulting from the reasonable 6Z 7/3/93 analysis is also fairly satisfactory but the accuracy of the cloud base forecast has not been checked. The T+6 forecast from 0Z 8/3/93 is also reasonable and has more cloud over the North Sea than the LAM. The 6Z 8/3/93 analysis is deficicient in cloud but not as bad as the 6Z 6/3/93 analysis and is much better than the 6Z 8/3/93 LAM analysis.

During this period the low cloud cover in the 0Z LAM analyses was also compared with that in the previous T+24 hour forecast verifying at the same time and all examined showed less cloud in the analysis than the T+24 hour forecasts. The forecast and analysis verifying at 0Z 6/3/93 are shown in figure 15 as an example.

4. MOPS intervention for period 4/3/93 to 9/3/93

In the operational runs of the mesoscale model, MOPS data is only included if the forecasters have run the system interactively. It is not run automatically as a back-up system due to the problems with defining cloud top and cover of low cloud. This means that sometimes MOPS data may not be included in the operational assimilation system, in practice on about 15% of occasions.

However even if the forecasters run the interactive MOPS sessions they may not have actually intervened to correct the low cloud analysis errors so that the resulting MOPS humidity profiles may not have the beneficial results shown in the 4/12/91 case and instead produce the null benefit of the automatic system seen on that occasion.

Therefore it is possible that the skill in analysing and forecasting stratocumulus may be related to the skill of the intervention in the MOPS system and whether or not the data was actually produced.

The intervention forecasters make a few comments on the actual intervention performed in an interactive MOPS session. These notes are reproduced in Appendix B for the period 4/3/93 to 9/3/93. The 21Z, 0Z and 3Z sessions are all undertaken by the same night shift forecaster but the 6Z session occurs at the start of the next day shift. It can be seen that, although there are comments for all the night intervention sessions, there are none for the 6Z 6/3/93 and 6Z 8/3/93 analyses so it is not clear whether any intervention was performed on those occasions. On further investigation it was found that no MOPS data were created for 6Z 6/3/93. MOPS data were produced for all other times of interest in the period (including 6Z 8/3/93), though the extent of the intervention can only be surmised from the forecasters' comments.

It will be noted that there are no comments about correcting the cloud top analysis until the MOPS sessions for the 0Z 7/3/93, 6Z 7/3/93 and 0Z 8/3/93 forecasts. In the sessions affecting the 0Z and 6Z 6/3/93 forecasts it is not clear whether there was any attempt to correct the cloud over England and Wales. In the comments for the sessions affecting the 0Z and 6Z 5/3/93 forecasts it is not clear whether the modifications were made to cloud tops or bases but it is clear that care was taken over the analysis.

From the forecasters' comments it is possible that there is some correlation between the MOPS intervention and the skill of the analyses and forecasts but this would require further investigation.

5. Impact of MOPS and radiosonde humidity data on analyses and forecasts for 6Z 6/3/93, 7/3/93 and 8/3/93

The separate contributions of MOPS data and radiosonde humidity data to the analyses and 6-hour forecasts valid at 6Z on the 6th, 7th and 8th have been established by extra experiments where these data types were separately omitted from the assimilation. The results are summarised in Figures 16, 17 and 18.

The general conclusion from these 6 model runs is that radiosonde humidity data have degraded the analyses and 6-hour forecasts, while MOPS data have been significantly beneficial to the analysis and marginally so to the 6-hour forecasts. It is possible that the benefit from MOPS data in the forecast would be greater if the radiosonde humidity data were omitted.

The worst example of harm from radiosonde humidity data is to the t+6 from DT 0Z 7/3/93. Compare figures 17b and 17c. The analysis at 6Z 8/3/93 was also badly affected in northern England and Ireland (Figures 18e and 18f).

MOPS data give more cloud in the t+6 valid at 6Z 7/3/93 (Figures 17b and 17d), particularly over Ireland and the English Channel. There is little impact at t+6 on 6/3/93 and 8/3/93.

The operational analysis at 6Z on the 8th has more cloud over the North Sea and central England than the run without MOPS. The analysis without MOPS data on the 7th is deficient in cloud over Wales and south-west England relative to the operational run. There is little improvement at 6Z on the 6th because MOPS data were not prepared operationally. The slight impact over Ireland comes from 3Z MOPS data (Figures 16e and 16g)

6. Further investigation of 0Z 8/3/93 and 6Z 8/3/93 forecasts

Further investigation has been carried out into the relative performance of the 0Z 8/3/93 and 6Z 8/3/93 mesoscale forecasts.

6.1 Operational Forecasts

There was still low cloud cover over most of the British Isles at 12Z 8/3/93 as can be seen from figure 19 but the cloud is beginning to recede northwards and has retreated to northwards of a line from the Bristol Estuary to the Humber by 1443 as can be seen from figure 10. The 0Z LAM has produced a reasonable forecast although the cloud edge is slightly too far north at 12Z and the 0Z mesoscale forecast is slightly better. However the 6 hour forecast from the 6Z mesoscale run is far less accurate with most of England and Wales erroneously cloud free.

The operational assimilation was checked and it was found that MOPS data was included in both forecasts so that, although there are no comments from the forecaster,

the 6Z 8/3/93 MOPS session was run. However there is no way of knowing whether any intervention was performed to correct deficiencies in the cloud cover and top analyses.

At 0Z all the standard UK upper air stations reported ascent data, Camborne, Boulmer, Long Kesh, Aughton, Hemsby and Herstmonceux. However at 6Z there was a slightly different group of stations - Boulmer, Long Kesh, Aughton, Aberporth, Larkhill and Herstmonceux. Additionally there was an ascent from Waddington at 3Z. There was also an ascent from Shoeburyness that morning but it was not assimilated in the 6Z run due to its late, 8Z, launch.

In figures 20, 21 and 22 some of the observed and analysed ascents are compared. It can be seen that at 0Z 8/3/93 the observed ascents show a well resolved saturated (or near saturated, see later) cloud layer about 50mb deep in most ascents whereas by 6Z those in the east are much drier indicating thinner or dispersed cloud, reflecting the clearance of the cloud from the southeast during that morning. The analysed ascents also reflect this trend but have many limitations. The eastern 0Z ascents, although saturated do not have a thick enough cloud layer. The 6Z Herstmonceux ascent is too dry and closer to the structure of the later observed Shoeburyness ascent.

6.2 Sensitivity to assimilated humidity data

The 0Z and 6Z mesoscale forecast and assimilation were rerun with the MOPS data removed. From figure 19 it can be seen that there is very little difference in the forecasts valid at 12Z from the operational forecasts. The 6Z forecast was also rerun with sonde humidity data removed and MOPS humidity data included and finally with both sonde and MOPS humidity data removed. It can be seen from figure 23 that the inclusion of the sonde humidity data has a positive impact in the SW approaches but a negative impact over the North Sea. When the MOPS data is included but the sonde humidity data is excluded the forecast is much better. There is a positive impact from the MOPS data over northern England and Wales but the cloud edge is still slightly too far north. It can be seen that again the sonde data is degrading the impact of the MOPS data on the forecast of cloud cover.

In figure 24 the 6Z 8/3/93 analysed ascents from these additional forecasts are shown and should be compared with those in figures 21 and 22. The Crawley and Hemsby ascents from the forecast with MOPS data excluded but sonde humidity included have a drier inversion than the observed Herstmonceux ascent and are closer to the Shoeburyness ascent which was probably out of cloud by 8Z. From comparison with the ascents with both sonde and MOPS humidity data excluded it can be seen that the assimilation of the sonde data has correctly dried out the sub-inversion air and increased the humidity at the inversion base at Crawley. None of these analysed ascents, or the operational ones, have saturated air under the inversion. However when the MOPS data is included but the sonde data excluded the ascents are much closer to saturation and are in fact saturated at Hemsby. Unfortunately the air is too moist and cold under the inversion so that the temperature structure is not consistent with the humidity structure and additional, possibly spurious, moist layers have appeared between 900

and 600mb (This is probably due to too little intervention in the MOPS sessions so that tops and bases derived from surface and satellite data are not consistent, leading to multiple layers).

6.3 Comparison of observed cloud cover and that derived from sonde profile

In order to gain greater understanding the consistency of the sonde humidity data with the unified model cloud scheme and observed surface cloud cover was investigated.

In the unified model cloud scheme a critical relative humidity RH_c is defined below which the cloud fraction is zero. Above the critical relative humidity the cloud fraction is determined as a function of the actual and critical relative humidity (Unified Model Documentation Paper No 29 equations P292.18 to P292.21). In the mesoscale model RH_c=0.925 for the bottom 7 levels and 0.85 for the remaining levels. The total cloud cover C_t is calculated from the cloud cover, c_n, in each layer by using the random overlap assumption -

$C_t = 1 - \prod_{n=1}^{n=27}(1 - c_n)$

By taking the sonde humidity profile averaged over model layers, a cloud cover was calculated for each layer and a total cloud cover calculated and compared with the surface observation of cloud cover. From the 0Z sondes there was a bias of -2.7 oktas but reducing to -2.5 oktas for stations reporting full cover. However, for the 3Z and 6Z sondes there was a bias of -4.4 oktas increasing to -6.4 oktas for stations reporting full cover. As examples, the 0Z Herstmonceux ascent had three layers with calculated fractional cover greater than zero, none saturated, a maximum cover of 0.8, total cover 0.87 and observed cover of 1.0 whereas the 0Z Hemsby ascents also had three layers with calculated cover greater than zero, none saturated, maximum cover 0.15, total cover 0.31 and observed cover of 1.0. At 6Z the Herstmonceux ascent had only one layer with calculated fractional cover greater than zero, none saturated, a maximum cover of 0.02, total cover 0.02 and observed cover of 0.625.

There was only one sonde at 3Z (from Waddington) and this had a large deficit in calculated cloud cover (calculated fractional cover of 0.12 compared with full cover in the surface observation). Its accuracy is suspect as there is no evidence from the surface charts that it is on the edge of, or at a break in, the cloud.

The locations of the radiosonde stations referred to in this paper are shown in figure 25.

6.4 Sensitivity to physical parametrisation schemes

The 6Z 8/3/93 assimilation and forecast was rerun to investigate the sensitivity of the prediction of low cloud cover to changes in the physical parametrisation schemes.

It had been found in section 2.2.2 and Ballard et al 1993 that the model predicted more low cloud cover when the non-local mixing scheme was included with the new convection scheme with parameters reduced to the values used in the LAM and climate models. The assimilation and forecast including MOPS and sonde humidity data was

rerun with these reduced parameters. There was a slight improvement in the forecast as can be seen by comparing figures 26b) and 27b) with figures 14e) and 23a). The assimilation and forecast was also rerun with the reduced parameters and excluding the MOPS data but including the sonde data. There was very little impact on the analysis but a slightly greater impact on the forecast as can be seen by comparing figures 26c) and d) and figures 27c) and d).

The climate model uses different values of critical relative humidity than the mesoscale model - equivalent to RH_c=0.95 at level 1 and 0.85 for all the upper levels. Theoretically one would expect that the critical humidities should be higher for models with higher vertical resolution such as the mesoscale model compared with the LAM and climate models. However, in order to try to reduce the inconsistency between the sonde data and the cloud scheme found in section 5.3, these new climate values were tried in the mesoscale model ie the critical value was increased in level 1 and decreased in levels 2 to 7, the critical levels for stratocumulus. This could only be tested without MOPS data as that has relative humidity values derived from cloud fraction using the model cloud scheme and the relative humidity needs to be recalculated if the cloud scheme is changed. By comparing figures 26c) and e) and 27c) and e) it can be seen that the reduced critical relative humidities result in more cloud in the analysis and forecast as would be expected. The forecast was also rerun using the reduced critical relative humidities and the reduced climate parameters. As can be seen by comparing figures 26 and 27 c), d) e) and f) this has produced a greatly improved analysis and forecast cloud cover. The bases are also in good agreement with the observations (between 1000-3000ft).

6.5 Conclusions from sensitivity studies for 6Z 8/3/93

From the assimilation sensitivity studies in section 6.2 it was found that the inclusion of sonde humidity data degraded the impact of the MOPS data. In section 6.3 it was shown that the cloud cover derived from layer averaged sonde humidities was lower than the surface observations of cloud cover. This explains the results of section 6.2 since the sonde humidities, consistent with zero or low cloud cover, will nudge the model fields away from full cloud cover. The MOPS data, where relative humidities are derived from cloud cover observations using the model cloud scheme, are consistent with full cover and will nudge the model towards full cover. It remains to be explained why the few sonde profiles appear to have a greater impact then the MOPS profiles available at every model gridpoint.

From the sensitivity studies in section 6.4 it can be seen that with reduced critical humidity values and the reduced convection parameters, the forecast areas with cloud cover greater than zero agrees well with the observed area of full cover. However in the standard forecast the analysed and resulting forecast humidities are too low to produce significant cloud cover. The modifications to the physical parametrisations tested here allow more cloud to be produced from the same basic data.

Obviously the model cloud scheme, in particular the critical relative humidities, could be tuned to ensure that the layer averaged sonde humidities were consistent with surface

observed cloud cover so that more cloud is analysed and forecast in the short period forecasts. However this can be dangerous if in fact the problem lies with the accuracy of the sondes themselves or the pre-processing of the observations to form layer averages as it may upset the longer range climatology and internal consistency of the model.

7. Discussion

It was shown in section 2 that the mesoscale model can give good forecasts of stratocumulus which are improved with the benefit of MOPS humdity profiles derived with the benefit of human intervention to correct deficiencies in the current objective scheme. The forecast is also sensitive to the physical parametrisations and more stratocumulus was produced over the North Sea when the boundary layer mixing was performed by the non-local scheme.

However from section 3 it is obvious that the operational forecasts are generally unreliable despite some excellent forecasts. In the period studied the poor forecasts are generally related to poor initial analyses. There is a lack of low cloud in the analyses and a corresponding underprediction of low cloud cover. The mesoscale model is no worse than the LAM and on occasions is more accurate.

In sections 2, 5 and 6 it was shown that the use of radiosonde humidity data reduced the impact of MOPS data in the analyses and forecasts. In section 6.3 it was shown that the cloud cover derived from layer averaged radiosonde profiles was low compared with the surface observations.

In section 6 it was also shown that modifications to the model physical parametrisations can result in the production of more cloud in the analyses and forecasts even without the inclusion of MOPS data.

Potential contributory factors to lack of cloud are:-

Related to data and data preparation

- Poor detection of low cloud by radiosondes. Underreporting of humidity in the boundary layer cloud. No requirement to report thickness of saturated layer - ie level at which sonde enters and leaves saturation.
- Limitations of layer averaging of sonde humidity
- Poor MOPS analysis of cloud cover and cloud top, particularly the latter.
- Lack of surface cloud cover observations. No sonde data within cloudy central England.

Related to assimilation technique

- Ineffective use of MOPS data relative to sonde data.

- Excessive spreading of unrepresentative sonde data (no sonde data within cloudy central England).
- No attempt to initialise cloud condensate.

Related to model formulation

- Inconsistency between observed layer averaged relative humidity and cloud cover and the model's cloud scheme.
- Clouds too thin to be resolved by the model.
- Inadequate physics.
- Poorly defined inversion, error in temperature structure.

These points obviously need more explanation.

- **Poor sonde data.** The ability of sondes to accurately detect relative humidities at or near saturation needs to be quantified. It is understood that they are generally poor in the boundary layer - the most vital height - and underreport the humidity. A Betts, personal communication, states that there were problems during ASTEX (Azores stratocumulus experiment) with the accuracy of sonde measurements. Thompson 1989 reports that Vaisala RS80 had 7% deficit in early trials in low cloud which was reduced to 3% by a change in sensor coating. If TEMP reports do not have to contain measurements at base and top of saturated layers, ie do not correctly define the depth of the saturated air, the layer averaged sonde humidities will also be an underestimate of the true layer averaged humidity.
- **Limitations of layer averaging of sonde data** The sonde humidity profiles are averaged to model layers before use. If cloud layers are thinner than the model layers this will result in less than 100% layer average humidity and hence less than full cloud cover.
- **Poor MOPS cloud analysis.** The skill of the analysis and forecast may depend on the care taken over the intervention required to correct cloud top heights. When the cloud layer is well defined in the MOPS data with consistent tops and bases, in agreement with the inversion height, this may overcome problems with the assimilation of the sonde data. MOPS sets a minimum stratocumulus thickness of 200m or 500m depending on the type of surface cloud reports that are available (Wright 1993). This will help to maintain thin cloud not resolved in the sonde data (however it may maintain the cloud for the wrong reason if the cloud is really thinner than 200m).

- **Lack of cloud cover observations.** There are generally no observations of cloud cover over Northern France at night leading to problems with the MOPS cloud analysis in that region as it will depend on the first guess and satellite derived cloud cover. The surface observation charts for the morning of 7/3/91 also show a reduction in the number of reports from normal. There are also no radiosonde ascents in central England - an additional sounding in the Birmingham area would potentially be useful.

- **Ineffective use of MOPS data relative to sonde data.** MOPS profiles are produced at every model gridpoint but there are relatively few sonde profiles. However the sonde data seems to override the impact of the MOPS data as seen from section 5. The relative weightings of the two data sources and their interactions in the data assimilation scheme need to be investigated.

- **Excessive spreading of unrepresentative sonde data.** If the sondes are on the edge of the cloud deck or in the cloud free regions it is possible to imagine that this could remove cloud if the region of influence spreads into cloudy regions. However the assimilation increments are in terms of differences between forecast and observed values so if the model agrees with the observations in the cloud free areas there should be no assimilation increments. Unfortunately if the sondes are undermeasuring the humidities and the model generally has a higher level of moisture than the observations, particularly in partially cloudy or thin cloud regions, this will lead to a general reduction in the areal cloud coverage. This could have been a particularly critical problem at 3Z on 8/3/93 when the only sonde had a large deficit in cloud cover calculated from its humidity profile compared with the surface observation.

- **No initialisation of cloud condensate.** The data assimilation scheme currently only assimilates humidity data and there is no attempt to modify the cloud condensate fields. As the model prognostic variable is total water (ie specific humidity plus condensate) this mean that too little total water may be inserted when trying to add cloud from the observations and too little may be removed when trying to remove cloud.

  However during the early stages of the New Mesoscale Model development, a scheme to reinitialise the cloud cloud condensate during the humidity assimilation was tested on all the mesoscale trial cases (Macpherson personal communication). This calculated a cloud condensate consistent with the adjusted humidity field using the model's cloud scheme. It had negligable impact so this factor does not appear to be important.

- **Inconsistency between model's cloud scheme and reality.** If the sonde data is accurate it appears that the model requires too high a relative humidity for cloud formation.

- **Clouds too thin to be resolved explicitly.** The model's skill may be related to the thickness of the cloud ie if the observed cloud layer is thick it may be easier to analyse and maintain it than if it is just a thin layer. However ideally a good analysis and sub-gridscale parametrizations should be able to deal with thin cloud layers. It is likely that the current subgridscale cloud scheme is not correctly dealing with subgridscale cloud due to stratification and non-random variations in temperature and humidity structure. In the good 0Z 8/3/93 case there was a well defined cloud layer in the observed ascents whereas in the 6Z 8/3/93 ascents there was at most one point near saturation in the eastern ascents. In figures 28,29 and 30 some of the T+18 forecast, T+0 analysed and actual ascents valid at 0Z 6/3/93 are compared. It can be seen that in the good forecast from 6Z 5/3/93 the cloud is thicker in the northern ascents than in the analyses and observations. In figure 31 the same selection of observed 0Z 7/3/93 ascents are shown. Again the cloud layers are thin apart from in the west.

- **Inadequate physics.** It was shown in sections 2 and 6 that the forecast stratocumulus cloud cover is sensitive to the model formulation. In particular it appears that use of the non-local mixing scheme with convection parameters reduced to those used in the other models will produce more boundary layer cloud.

  In section 6 it was shown that there is an apparent inconsistency between the sonde data and the cloud scheme. However it is risky to tune the model's scheme to the sonde data (such as by changing the critical relative humidities - as was done in section 6) if the latter is under-reporting the real values of relative humidity. The whole issue of whether the model is too moist with respect to observations still needs to be resolved. Given suitable initial conditions the model can give good predictions of stratocumulus but it is still possible that the model moisture budget is wrong.

  The issue of correctly parametrising unresolved, vertically thin clouds was raised above and it seems likely that improvements are required.

  Finally, the model's microphysical scheme is very simplified, in particular the important dependence on variations in cloud condensation nuclei concentrations is neglected and the cloud phase is treated in an ad hoc fashion.

- **Error in temperature structure.** The forecaster's guidance comments produced by CFO for the outstation forecasters, see Appendix C, on the 6Z 8/3/93 forecast state that the mesoscale model 'inversion is insufficiently developed and not cold enough allowing more ready breaking of cloud, hastened by enhanced daytime heating'. However following the investigations in section 6 this does not seem to be the cause of the major problems in this case.

The poor operational forecasts are not just due to one cause but a combination of the problems described and probably other as yet unidentified ones. Further investigations are required. However from the investigations reported here the principle problem

seems to be related to the use and quality of the radiosonde humidity data and potential inconsistencies with the model cloud scheme.

8. Recommendations

This is the first brief attempt to understand operational problems in forecasting stratocumulus using the unified model forecast and assimilation system. Various recommendations are listed below.

- **Radiosonde Humidity Accuracy**

  The accuracy of radiosonde humidity measurements needs to be clarified so that it can be taken into account in the design of the assimilation scheme and cloud parametrisations.

- **Vertical Resolution of radiosonde humidity reports**

  It would be useful if standard reporting practice gave the base, top and depth of cloudy layers and their humidities - possibly by reporting the height at which the sonde entered and left regions with humidity greater than a certain value. However, it is possible that the requirement to report 'turning points' in the profile may give this information and this needs to be investigated.

- **Processing of Radiosonde Humidity data for the Assimilation**

  At present the reported profile is averaged vertically onto the model layers prior to assimilation. Thin cloud layers might be analysed better by the model if the maximum humidity in the layer was presented to the assimilation. Alternatively, in view of the results described in section 6.3, it would be worth investigating a scheme whereby the layer averaged radiosonde profile was scaled to ensure consistency with the surface cloud cover report. The model cloud scheme's relationship between cloud fraction and relative humidity could be employed.

- **Accuracy of MOPS cloud analysis**

  Greater care should be taken over the MOPS intervention in low cloud situations.

  The quality and frequency of operational intervention on MOPS analyses is variable. It is desirable to automate MOPS, so that more consistent analyses and forecasts can be obtained. An accurate scheme to detect low cloud cover and top must be devised. Promising progress with cloud top height assignment is reported by Hand(1993).

- **Assimilation of humidity**

  Possibly the impact of working in humidity mixing ratio or total water mixing ratio rather than relative humidity should be investigated. Beneath the inversion in well mixed conditions the assumption of an adiabatic profile may lead to a higher layer mean humidity than averages of relative humidity. Possibly the dry and warm air above the inversion should not be included in the same layer average as the sub-inversion air.

- **Adequate Testing**

  It is always difficult to test new schemes and systems on one case, as in the new mesoscale model trial. It would be useful to use the period 5/3/93 to 9/3/93 or similar periods of about 5 days length to study developments that will affect low cloud or fog.

- **Improved Physical Parametrizations**

  The lower convection parameters were not used in the initial operational version of the mesoscale model as it appeared that there was a tendency for that version to produce too much low cloud which had a detrimental effect on the screen temperature forecast and it suppressed some of the beneficial results from the new convection scheme. The overprediction of cloud cover and impact on screen temperature is partly due to the use of the random overlap assumption in calculating total cloud cover for the radiation schemes. The original concern about suppression of convection has gone since various corrections have been made to the convection scheme.

  Since operationally there is obviously a deficit in cloud cover, the reduced convection parameters should be considered for operational use and tested on some of these cases. Hopefully within the next year it will be possible to use the maximum or maximum random overlap assumption in the short-wave radiation scheme in the model which may reduce some of the temperature problems.

  It is possible that a new parametrisation for thin, unresolved (ie less than one model layer thick) clouds needs to be developed.

  The impact of revised critical relative humidities should be investigated further but only after the accuracy of the sonde data has been ascertained. The scheme for deriving cloud cover needs further investigation particularly in relation to thin, sub-layer thickness full cover clouds.

  The specifications of cloud condensate phase should be investigated. The fully prognostic mixed phase cloud and precipitation scheme may have some impact. The climate model parametrisations should be investigated further.

- **Routine Objective and Subjective Verification**

  It was shown in section 3 that the routine subjective and objective verification systems provided useful insight into the performance of the model. In particular the notes on synoptic situation allowed a period for study to be quickly chosen and the scoring indicated the overall performance of the model. The time-series of total cloud cover bias correctly indicated the skill of the model most of the time. However it was clear that there is a need to distinguish between cloud and fog, this may be possible by using these figures in conjunction with cloud base verification time-series. Total cloud base figures should be made available and these will be more meaningful if they are limited to reported bases less than 8000'

with an option to further limit the forecast base to be below 8000' as well. More detailed gross monthly statistics on cloud cover and base accuracy would also be useful.

- **Comparison with field study investigations of stratocumulus**

  Where possible field study investigations should be used to complement routine objective verification. The ASTEX data obtained during June 1992 should provide a good database for investigation and is being used to investigate and hopefully improve the performance of the ECMWF model. The Global and LAM analyses and boundary conditions for this period should be put on permanent retention.

- **Long Assimilations/forecasts with no radiosonde humidity data**

  It is evident from section 3 that it is not possible to investigate the true performance of the model from the operational system due to the lack of cloud in the analyses. Investigation of the climate model performance will give some guidance on the actual model as opposed to assimilation cycle performance. However, the climate model uses coarser resolution. It would be interesting to rerun the 5/3/93 to 9/3/93 forecasts without the inclusion of radiosonde humidity data. Global and LAM, as well as mesoscale, assimilation and forecasts would have to be rerun for the whole period due to the discontinuous assimilation/forecast cycles in the LAM and mesoscale models and the influence of boundary data. It may be possible to gain some insight by just rerunning the global assimilation and then selected global, LAM and mesoscale forecasts.

- **Further Investigation of Operational Performance**

  This report describes an initial investigation of the operational performance of the model. There have been changes to the operational system since the period investigated here.

  In particular on 9/3/93 the global model horizontal diffusion scheme was changed to be consistently 4th order for all variables rather than 2nd order for humidity and 4th order for all other variables. This was seen to have an impact on the humidity structure of the global model that will feed through into the higher resolution models through the assimilation cycle and boundary conditions.

  On 27/4/93 the non-local mixing boundary layer scheme and downdraught convection scheme were introduced into the operational LAM which may result in an increase in forecast low cloud cover following the results of section 2, 6 and Ballard et al 1993.

  Therefore the performance of the operational analyses and forecasts since that date should be investigated to see if the characteristics have changed and to shed further light on the problems highlighted in this paper.

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APPENDIX A. Extracts from CFO (Central Forecast Office) Subjective Verification of Mesoscale Model Forecasts for period 06Z 4/3/93 to 06Z 9/3/93.

DT	SCORE	SYNOPTIC SITUATION	COMMENTS
04/06	C	Ridge moving S followed by warm front	Much as LAM for ppn - lacking over N. Ireland - but more than LAM at 05/06Z over Lincs. Cloud on warm front mostly reasonable but SC missing England/Wales at first, continent later.
05/00	C	Warm front move South in NW flow	Much as LAM for ppn - too little mainly. Cloud misleading - too little over France - not low enough, esp E Anglia/Kent after noon.
05/06	C	warm front S coast ridge building	No frontal ppn. Temps too low S. UK. Cloud useful guidance but no better than 00Z LAM.
06/00	C	Anticyclone S. Ireland	Light Rain/drizzle NW Scotland as LAM. Unable to resolve sea inversion cloud fields. Hence cloud frames misleading and temps over Wales SW England in error.
06/06	C	Anticyclonic	Too much orographic ppn W. Scotland. Cloud frames very poor. - therefore temps too low overnight
07/00	C	Anticyclonic	Cloud frames poor - almost none shown most of UK cloudy - too much frost at start as a result and afternoon temps too high.
07/06	B	ANTICYCLONIC	LAM PRECIP BETTER TO T+12 IN W SCOT MUCH BETTER WITH 12 IN SE ENGLAND T+24. MIN TEMPS & CLD REASONABLE
08/00	A	ANTICYCLONIC	MESO CAPTURED 12 IN SW & E MIDLANDS. BOTH RATHER TOO MUCH PRECIP IN W SCOTLAND. BOTH NOT BAD ON CLD SITUATION. BUT TOO COLD IN SE ENGLAND.
08/06	C	Anticyclonic	SC clearance forecast but much too quick. Radiation upslope ST Pennines & Moor not F/C
09/00	C	S'ly	Showers in SW not forecast. Cloud frames very poor - not enough in SW, too much E Anglia
09/06	B	SE'ly (dry NE, wet in SW).	No additional useful guidance - neither model got the rain in SW Britain (GZRA at 0338Z at 19Z). Temps - good guidance. Blustery day in N & E so not surprising model got this right!

APPENDIX B. Extracts from CFO (Central Forecast Office) comments on intervention in MOPS (Mesoscale Observation Pre-processing System) for period 0Z 4/3/93 to 21Z 9/3/93.

ANALYSIS TIME FOR MOPS	COMMENTS
04(00Z)	Put in cld tops over Continent, 6 Oktas else, Ascents ok.
04(03Z)	——— // ———
04(21Z)	Added Radar Rain. Reduced Cld amount in SW. away from obs. by *0.5. Cld base lowered by *0.7.
05/00Z	Added Radar Rain Reduced All cld by *0.2. added cld tot of 4000 away from Warm Sector Amended Warm Sector profile based on Stornoway ascent.
05/03Z	Added Radar Rain 0260 amended for S of Front.
05/06Z	Radar pic had spurious echoes in so used 0500Z. Added cloud, low & medium to 03920 x 03882.
05/21Z	Filled In Holes in cloud cover to W of B.I. with 2/8 CLD.
06/00Z	No Satellite for 00Z. Used 22Z. Couldn't find 23Z satellite picture due to bizarre numbering scheme for sat pics. Recalculated cloud tops from sat pic.
06/03Z	Filled in hole in cloud cover to W of Ireland. with 4/8. Added cloud to Lerwick ascent.
06/21Z	Adjusted sat - temp. Added cld in N Sea and around Ireland, lowered cld top over all but N.
07/00Z	As 06/21Z
07/06Z RUN	- added cld over E N Sea & just S of Ireland. (cloud tops over UK too high (about 10000ft) but clicked wrong option & was unable to alter as program moves onto next option. Modified tephas - were showing 6-8/8 medium cld (took this out)
07/21Z RUN	Added cld over N. France and brought cld tops down from 8-16000ft to 4000ft over much of Eng and Wales.
08/00Z RUN	Very similar to above run.
08/03Z RUN	——— // ——— Also modified a Camborne, Herstmonceux and Valentia ascent - cld in below inversion and some cirrus at high lev
08/21	- added cld S of Ireland, 'toned down Rain'
09/00	- No 00Z Data - used 23Z. added cld S of Ire 'toned down rain'
09/03	- cloud 'tweaked', cld added, W of Brest. tephas modified.
09/21	- Analysis O.K. No changes

APPENDIX C. Guidance issued to outstations by CFO (Central Forecast Office) on mesoscale model forecasts with data times 6Z 7/3/93, 0Z 8/3/93 and 6Z 8/3/93. Written at about T+4 hours.

COMMENTS ON MESOSCALE DT 070600

PPN IN NORTHWEST UP TO T+4 SPURIOUS SO CONFIDENCE IN OROGRAPHIC PPN SUBSEQUENTLY IS LOW. MESO TEPHIS SHOW DEVELOPMENT OF DEEPENING CONVECTIVE LAYER UNDER INVERSION IN NORTHWEST TONIGHT CONSISTENT WITH TREND TO LIGHT SHOWERS (60 RAIN FROM SC?).
FRONTAL PPN MUCH AS LAM.
CLOUD OVER UK BETTER THAN MIDNIGHT RUN THOUGH NOT SAYING MUCH. AT 09Z RESOLUTION OF THE MAIN FEATURES OF THE PATTERN OF BREAKS IS POOR, EG THE OBSERVED BREAK OVER NORTHERN SCOTLAND FILLED IN, BREAKS OVER NORTHEAST ENGLAND COVERS MUCH OF NORTHERN ENGLAND ON MODEL, CLEARANCE LEAVING NORTHWEST FRANCE TOO EXTENSIVE ETC. FORECAST DETAIL EXPECTED TO REMAIN UNRELIABLE, THOUGH SIGNAL FOR MORE BROKEN CLOUD AHEAD OF FRONTAL BAND IN NORTHWEST APPEARS REASONABLE. CLOUD DISTRIBUTION OBVIOUSLY IMPACTS TEMPS WITH GENERAL LEVELS OK BUT DETAIL POOR. WINDS ACCEPTABLE WITH FRESHENING EASTERLY IN SOUTHEAST TONIGHT.

COMMENTS ON MESOSCALE DT 080000

MM AND LAM PPN FRAMES SIMILAR THROUGHOUT WITH HANDLING FRONTAL AND PRE-FRONTAL PPN IN NW. PATCHY PPN ELSEWHERE IS LARGELY ACADEMIC AND PROBABLY MORE REPRESENTATIVE OF BOUNDARY LAYER MOISTURE.

CLOUD FIELDS DO NOT DISPLAY THE USUAL RATHER UNRELIABLE MODELLING OF SHALLOW SUB-INVERSION SC AND AT INITIALIZATION AND T+3, MODEL CLOUD FIELDS CLEARLY DEFINE CLEAR SLOTS NEAR KENT COAST, INTO SW IRELAND AND OFF NE SCOTLAND. THIS GIVES SOME CONFIDENCE TO THE EVOLUTION AND SUPPORTS OUR NOWCAST GUIDANCE ON MOVEMENT OF CONTINENTAL AIR ACROSS SE BRITAIN.

CLOUD COVER OBVIOUSLY IMPACTS TEMPS WITH VALUES (SIMILAR TO MOS) IN THE RIGHT BALL PARK EXCEPT OVER OUTER HEBRIDES AND ORKNEYS WHERE RECOGNISED MODELLING ERRORS EXIST. WINDS ACCEPTABLE WITH VEER ACROSS COLD 'D' CLEARLY SIGNALLED ALTHOUGH PERHAPS A LITTLE FRESHER EASTERLY IN SOUTHEAST.

COMMENTS ON MESOSCALE DT 080600

SC REPRESENTATION OVER ENGLAND AND WALES UNREALISTIC TODAY, DESPITE REASONABLE IF RATHER TOO FAST INDICATION OF SC AREA AT 09Z. (MESO INVERSION INSUFFICIENTLY DEVELOPED AND NOT COLD ENOUGH ALLOWING MORE READY BREAKING OF CLOUD, HASTENED BY ENHANCED DAYTIME HEATING). 1015Z SPFU STILL SEEMS MORE LIKELY EVOLUTION, THOUGH REAR EDGE OF SC MAY REACH FURTHER NORTH INTO NE.ENGLAND SINCE OBS GRADIENT WINDS IN EAST ANGLIA RATHER STRONGER THAN FORECAST EARLIER.
REPRECENTATION OF CLOUD IN NORTH AND WEST, HOWEVER, LOOKS FAIRLY OK. OVERNIGHT, GOOD DEAL OF UNRESTRICTED RADIATION OVER MUCH OF BRITAIN, EXCEPT NW SCOTLAND, SEEMS REASONABLE.

FRONTAL RA/DZ IN NW PROVING WELL OVERDONE, MUCH MORE PATCHY IN NATURE AND TOTALS ON HIGH SIDE AWAY FROM OROGRAPHIC UPLIFT.

TEMPS IN NW ENGLAND LOOK 2-3C DEG OPTIMISTIC, POSSIBLY DEG OR SO ELSEWHERE IN NORTHERN ENGLAND, DUE TO MORE PERSISTENT SC.
OVERNIGHT TEMPS LOOK OK, BUT TEMPS MORE HOVERING AROUND ZERO THAN WIDESPREAD -1C. ISOL -2 OR -3C IN SHELTER WHERE BRISK GRADIENT FLOW DISCONNECTS FROM SURFACE, WITH PATCHES MIST AND SMALL PROB ISOL FOG PATCHES DEVELOPING AS OVER CONTINENT LAST NIGHT. TRAPPED INDUSTRIAL HAZE BECOMING WIDESPREAD IN SOUTH OVERNIGHT.

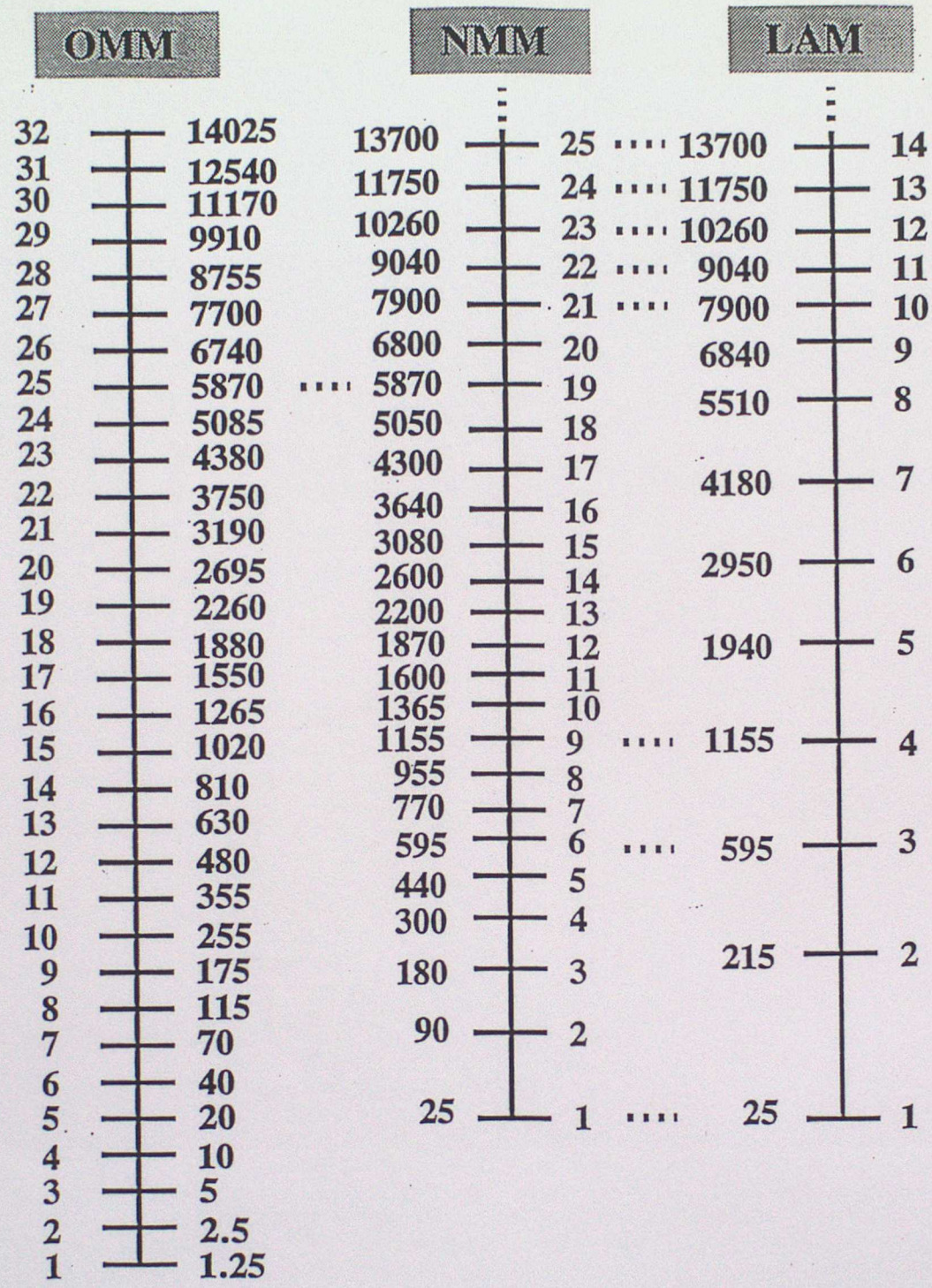


FIGURE 1. Comparison of model level heights in old mesoscale (OMM), new mesoscale (NMM) and Limited Area (LAM) models. Heights are in metres. All levels are shown for OMM but only the tropospheric levels are shown for the NMM and LAM. Heights for the NMM and LAM are approximate.

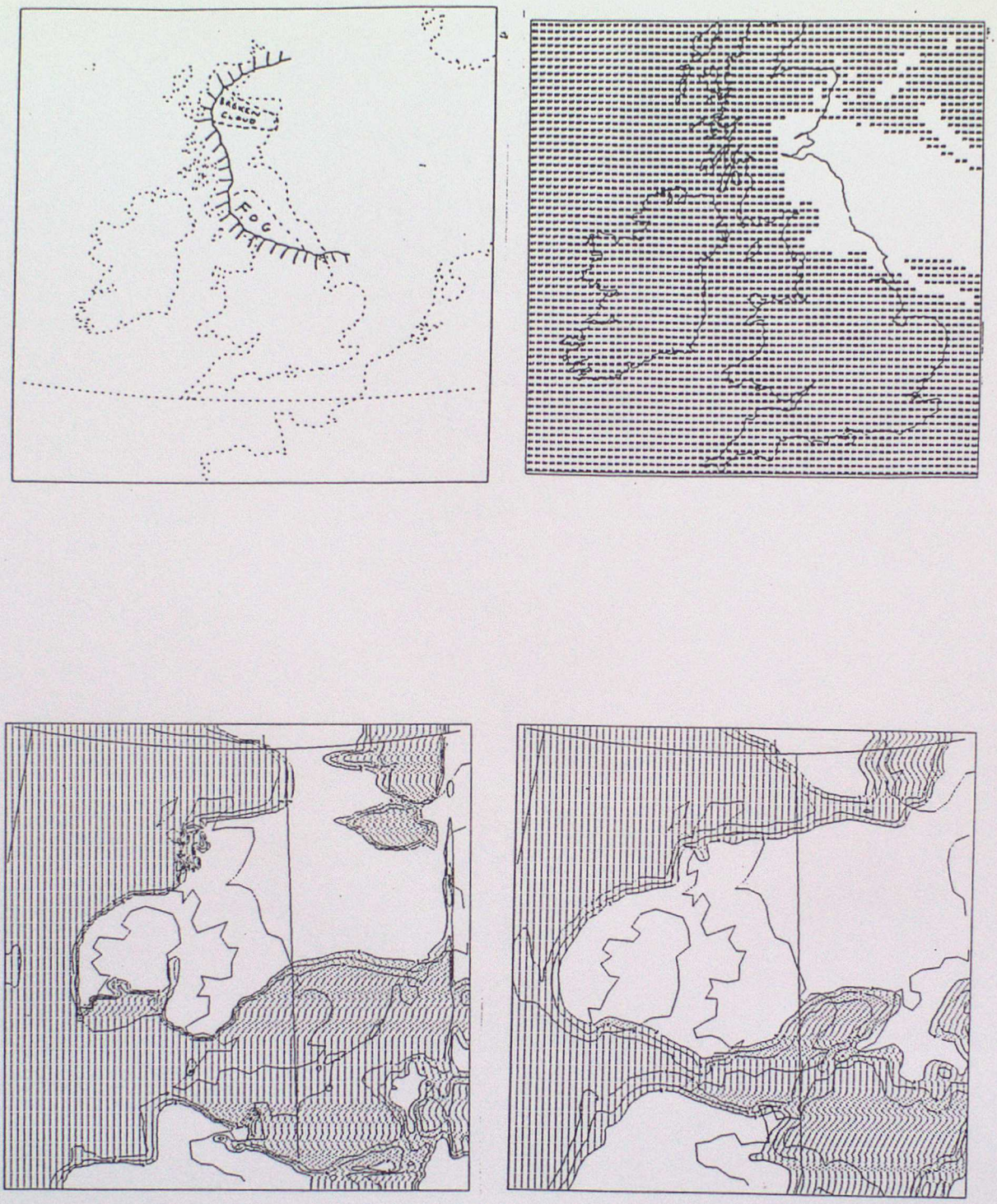
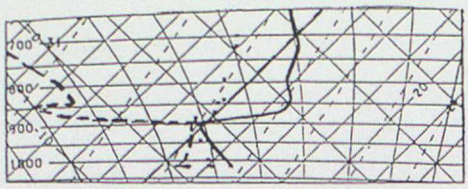
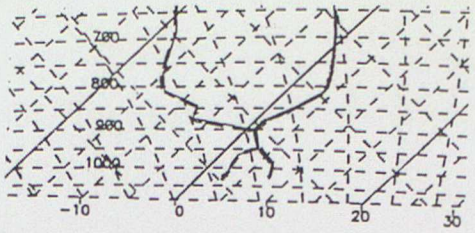


FIGURE 2. Comparison of observed and analysed total cloud cover at 0Z 4/12/91. The edge of areas with greater than 3 oktas cover is defined in the observations and areas with greater than 3 oktas cover are shaded in the analyses.
a) observed cloud edge, b) operational OMM analysis with benefit of IMI
c) NMM after 6 hours data assimilation, trial 1 version
d) LAM after 12 hours data assimilation, version 2.4.

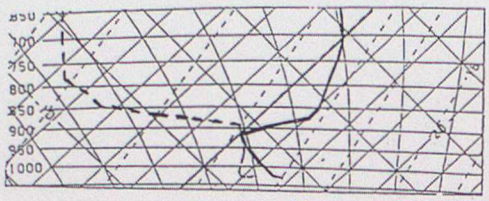
CAMBORNE



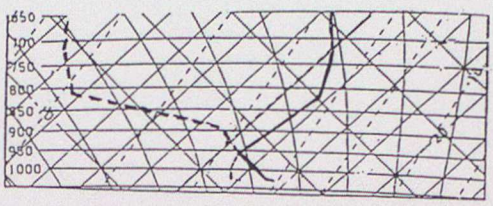
ACTUAL 0Z 4/12/91



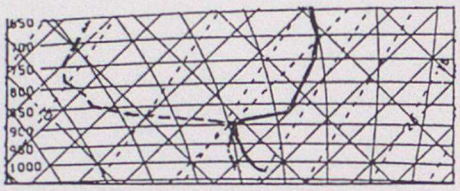
OMMIMI T+0 0Z 4/12/91



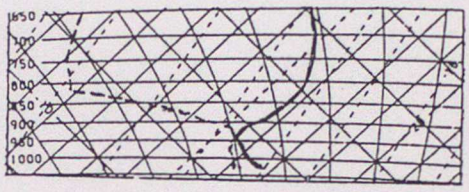
NMMAC T+0 0Z 4/12/91



LAMAC T+0 0Z 4/12/91

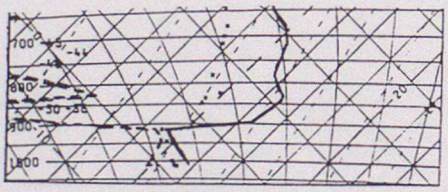


NMMAC T+6 6Z 4/12/91

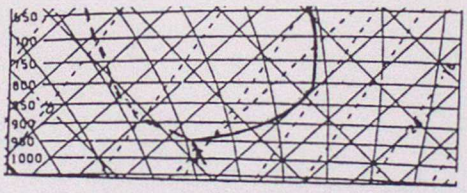


NMMLAM T+6 6Z 4/12/91

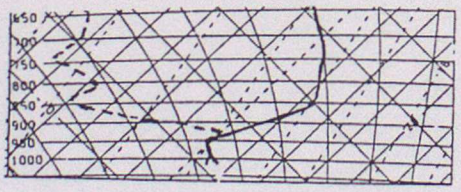
CRAWLEY



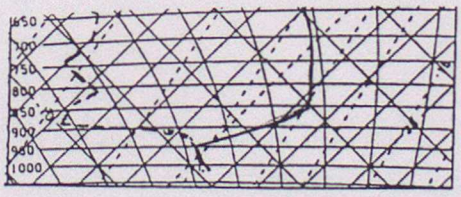
ACTUAL 0Z 4/12/91



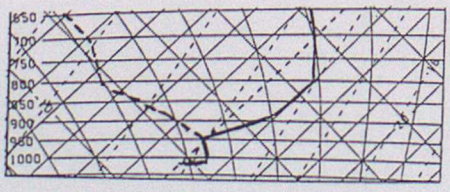
NMMLAM T+6 6Z 4/12/91



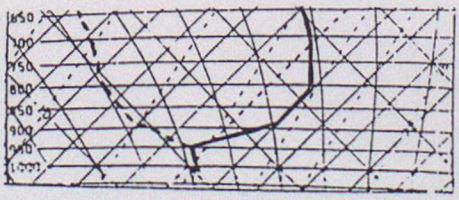
NMMAC T+0 0Z 4/12/91



NMMAC T+6 6Z 4/12/91



LAMAC T+0 0Z 4/12/91



LAMAC T+6 6Z 4/12/91

FIGURE 3. Comparison of actual and Trial 1 forecast Camborne and Crawley ascents for 4/12/91 case showing positive impact from assimilating radiosonde data at high vertical resolution in NMMAC which has best definition of cloud top and dry air above inversion.

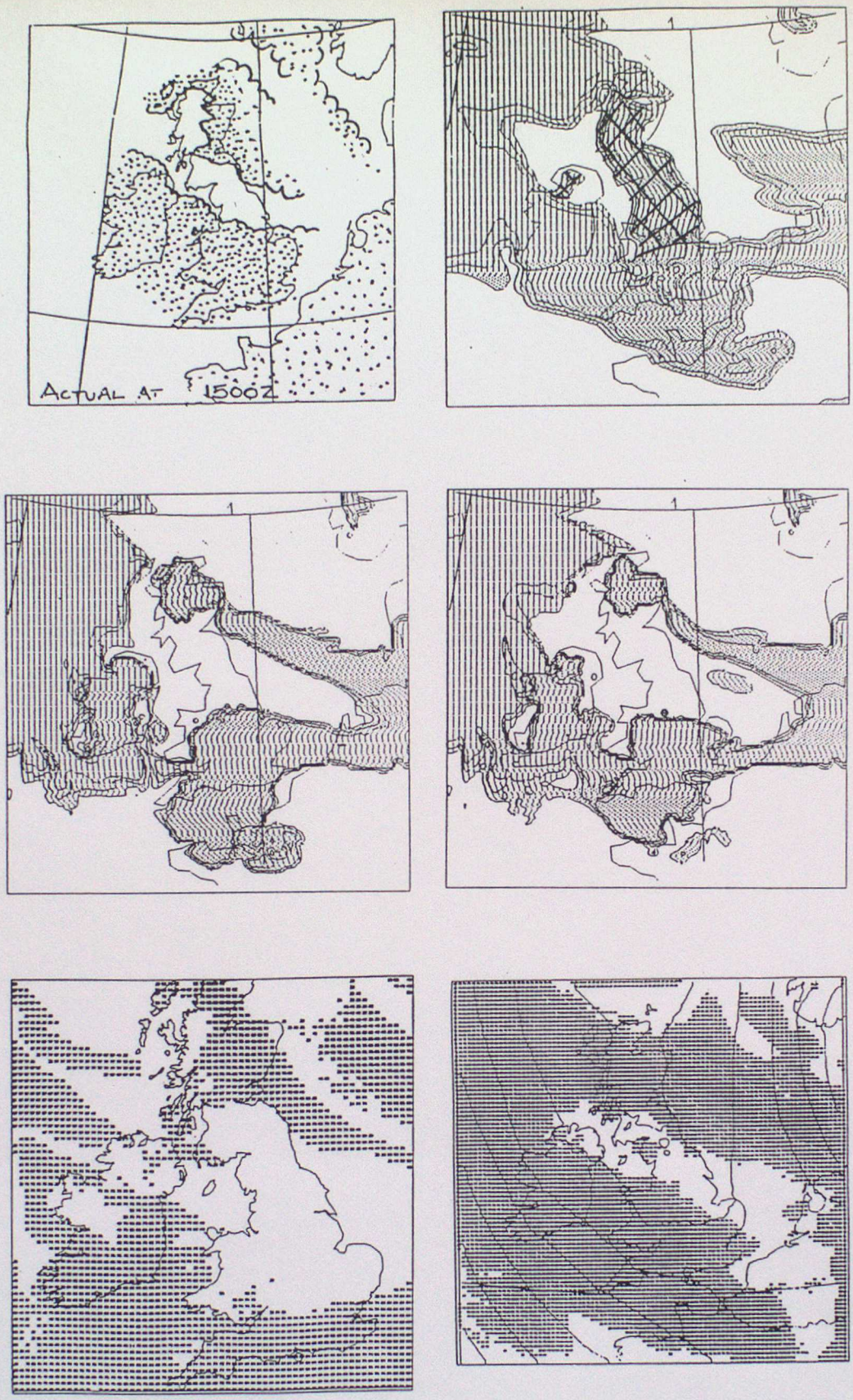


FIGURE 4. Comparison of observed and forecast total cloud cover at 15Z 4/12/91. The edge of areas with greater than 3 oktas cover is defined in the observations and areas with greater than 3 oktas cover are shaded in the analyses.

a) observed cloud edge

b) LAM 15 hour forecast, version 2.4. Hashed area marks cloud at level 1 only, ie fog

c) NMMAC 15 hour forecast, trial 1 version

d) NMMLAM 15 hour forecast, trial 1 version

e) operational OMM 15 hour forecast

f) OMMLAM 15 hour forecast

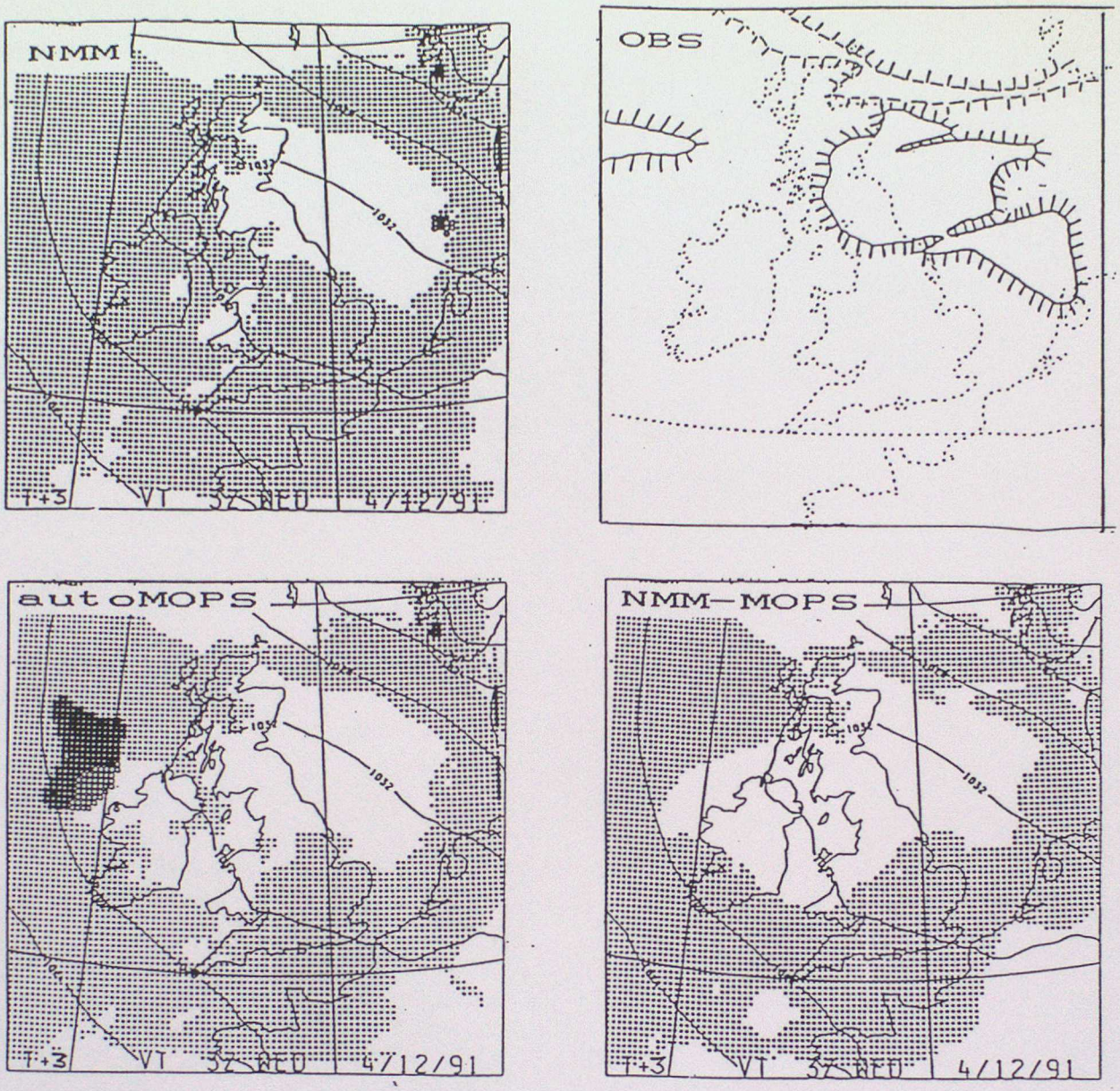


FIGURE 5.- t+3 cloud cover forecasts as in Figure 15 but demonstrating the impact of human intervention in MOPS (as in the NMM run) relative to a run with automatic MOPS data preparation (autoMOPS run).
The NMM-MOPS and OBS frames provide references.

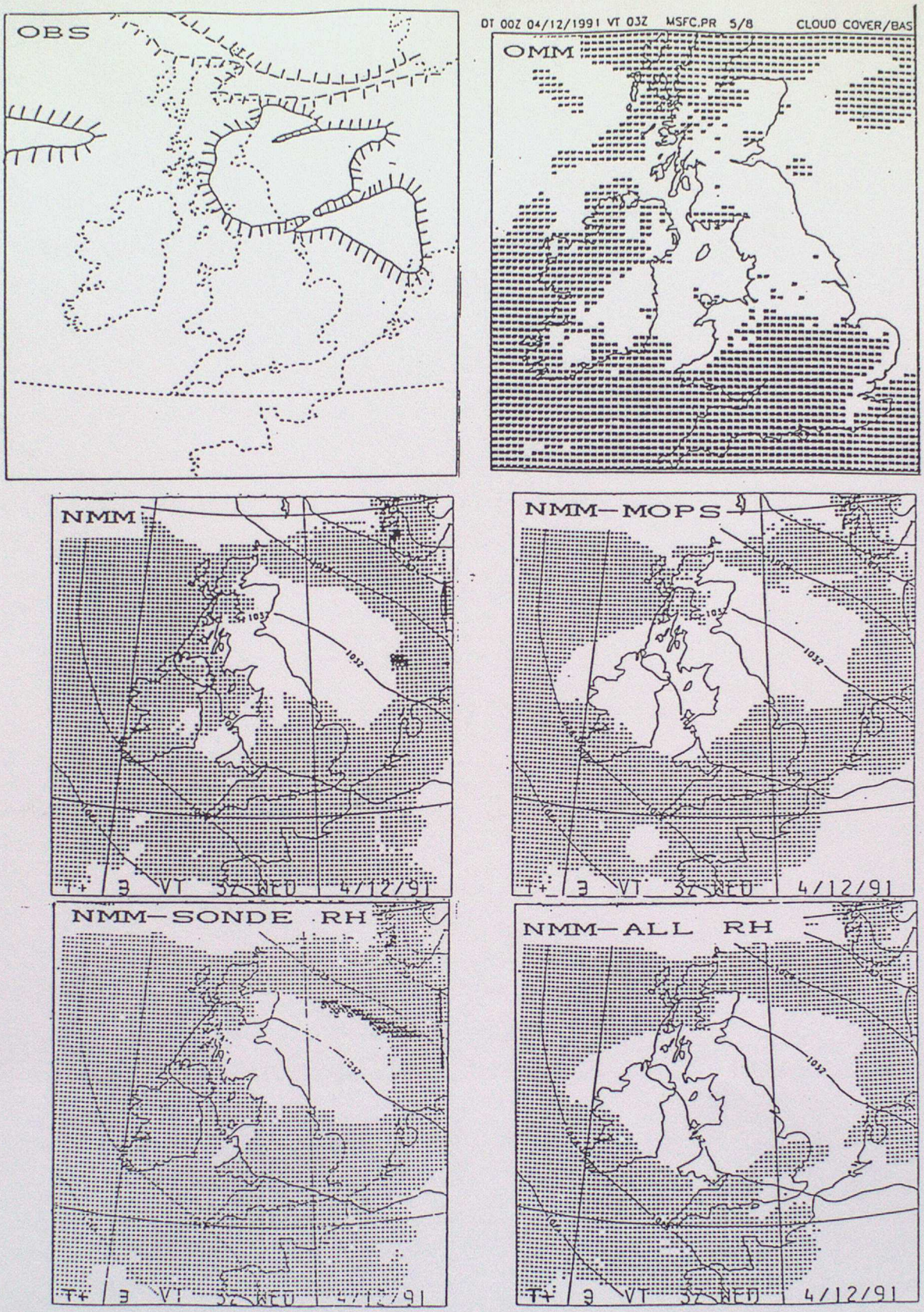
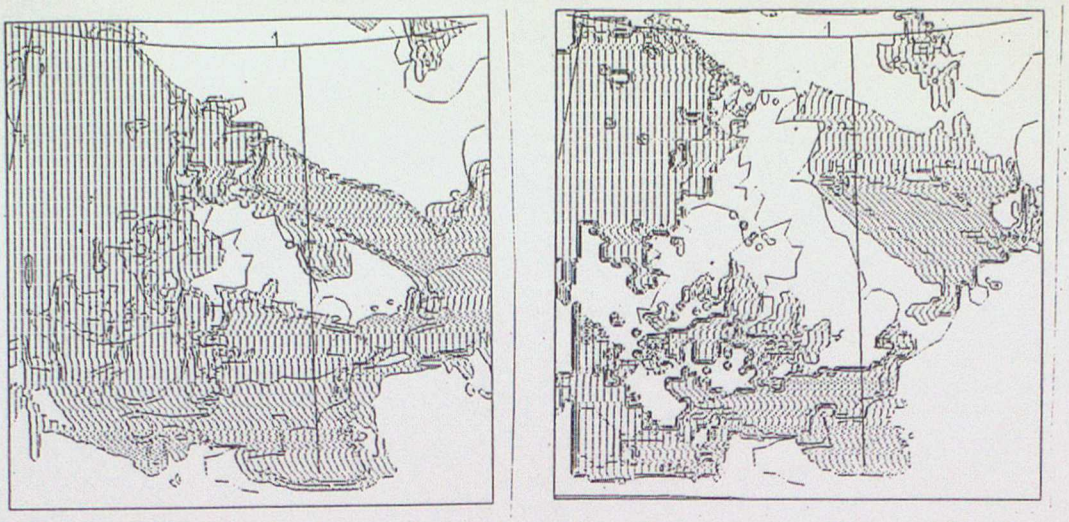


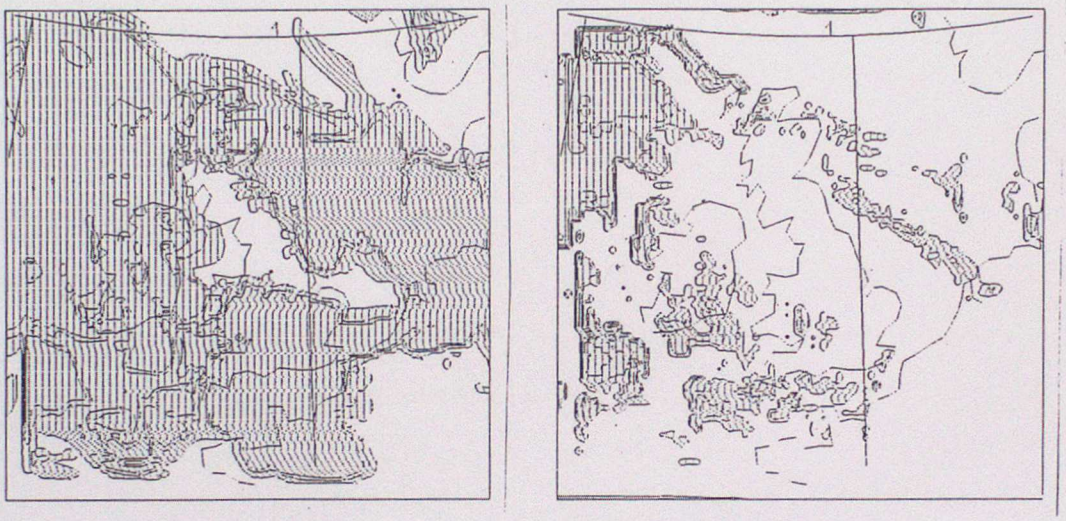
FIGURE 6. T+3 cloud cover forecasts valid at 3Z 4/12/91 and schematic verifying analysis of cloud edge from surface data and satellite imagery (labelled OBS). The OMM shows amounts of greater than 3 oktas, the NMM threshold is 4 oktas. The NMM output shows a dot for low cloud, an open circle for medium cloud and a black circle where both low and medium cloud coincide.

low cloud cover

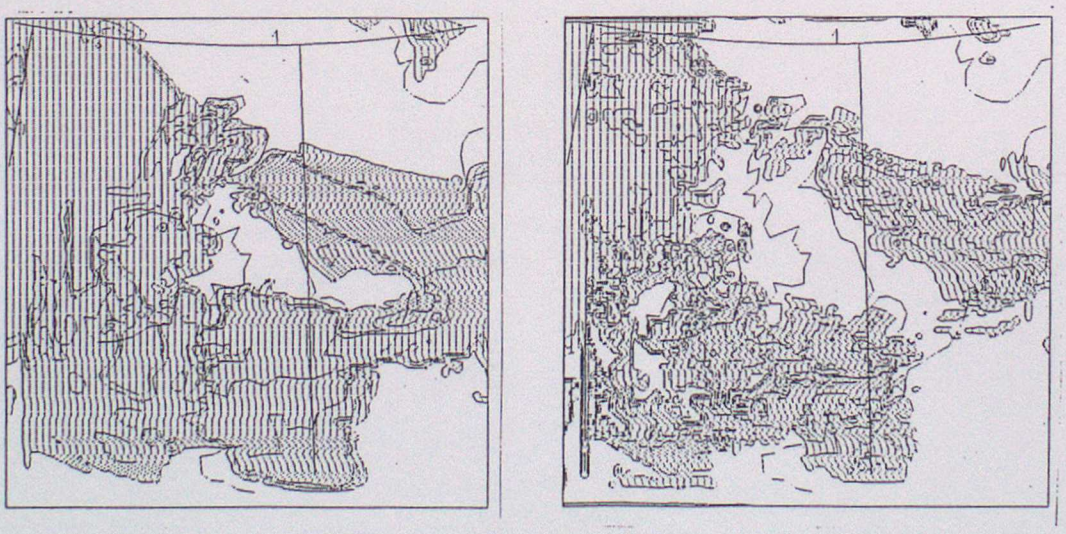
convective cloud cover



a) NMM , vn 2.7, with basic physics ie boundary layer, convection, gridscale precipitation and roughness length as trial 1.



b) as a) but with non-local boundary layer scheme included.



c) operational version of NMM , vn 2.7, ie as a) but with modification to boundary layer, convection, gridscale precipitation and roughness length included.

FIGURE 7. Comparison of 15 hour forecasts of low and convective cloud cover verifying at 15Z 4/12/91. Areas with low cover greater than 3 oktas are shaded and contour intervals at 3,5,7 and 9 oktas. Areas with convective cloud cover greater than 0.3 oktas are shaded with contour intervals 0.3,1,1.5 and 9 oktas.

FIGURE 8. 15 hour forecasts of total, low, medium and convective cloud cover verifying at 15Z 4/12/91. UM version 3.1 with additional climate physics changes. Areas with total, low or medium cover greater than 3 oktas are shaded and contour intervals are at 3,5,7 and 9 oktas. Areas with convective cloud cover greater than 0.3 oktas are shaded with contour intervals 0.3,1,1.5 and 9 oktas.

a) Total cloud cover

b) Medium level cloud cover

c) Low cloud cover

d) Convective cloud cover

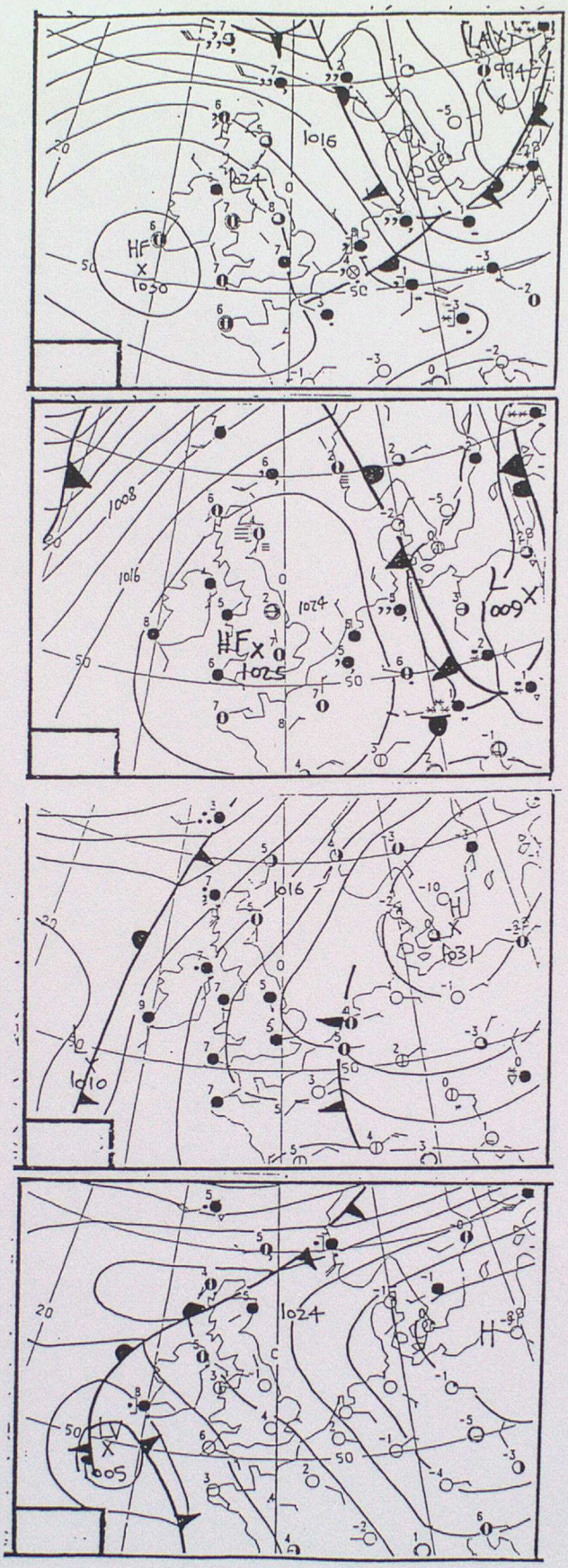


FIGURE 9. Synoptic Situation for period 0Z 6/3/93 to 0Z 9/3/93. Maps show mean sea level pressure, surface fronts and selected surface observations.
a) 0Z 6/3/93, b) 0Z 7/3/93, c) 0Z 8/3/93, d) 0Z 9/3/93

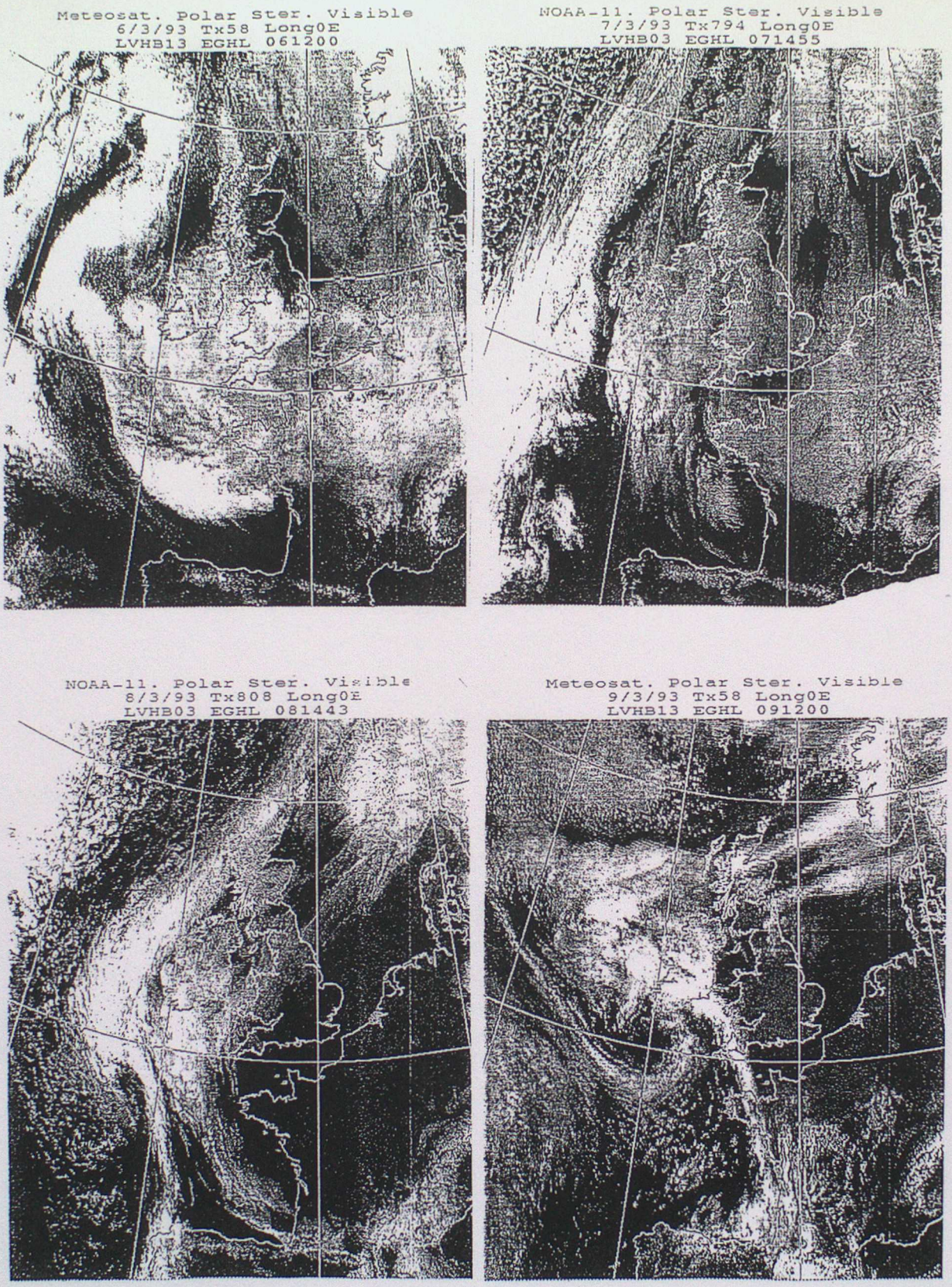


FIGURE 10. Visible satellite imagery for period 12Z 6/3/93 to 12Z 9/3/93. a) METEOSAT 12Z 6/3/93, b) NOAA-11 1455Z 7/3/93, c) NOAA-11 1443Z 8/3/93, d) METEOSAT 12Z 9/3/93.

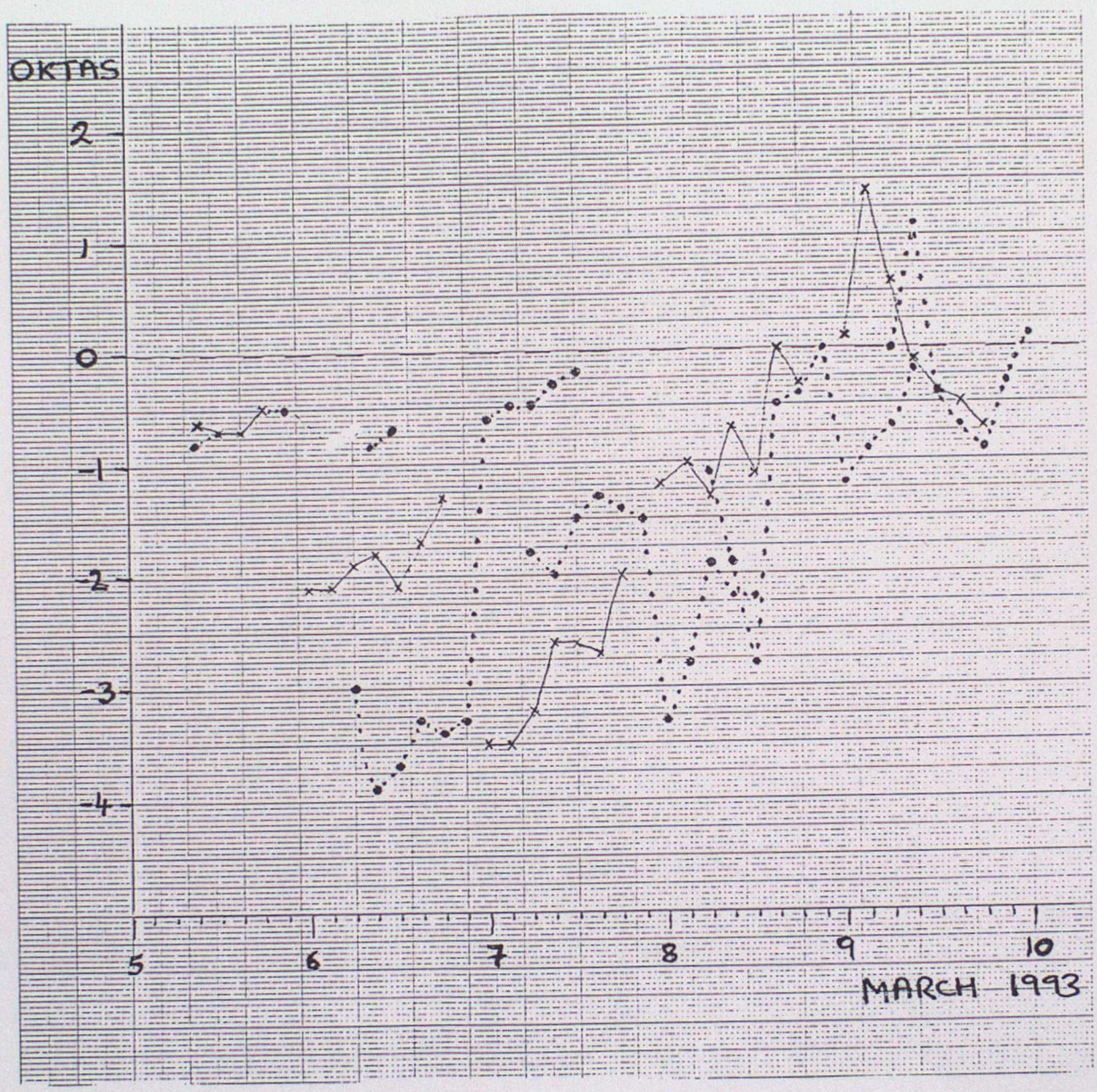


FIGURE 11. Mean error in total cloud cover from mesoscale model forecasts for period 5/3/93 to 10/3/93. Calculated for surface observing stations in UK area every 3 hours.

—— 0Z forecasts from T+0 to T+18

. . . 6Z forecasts from T+0 to T+30

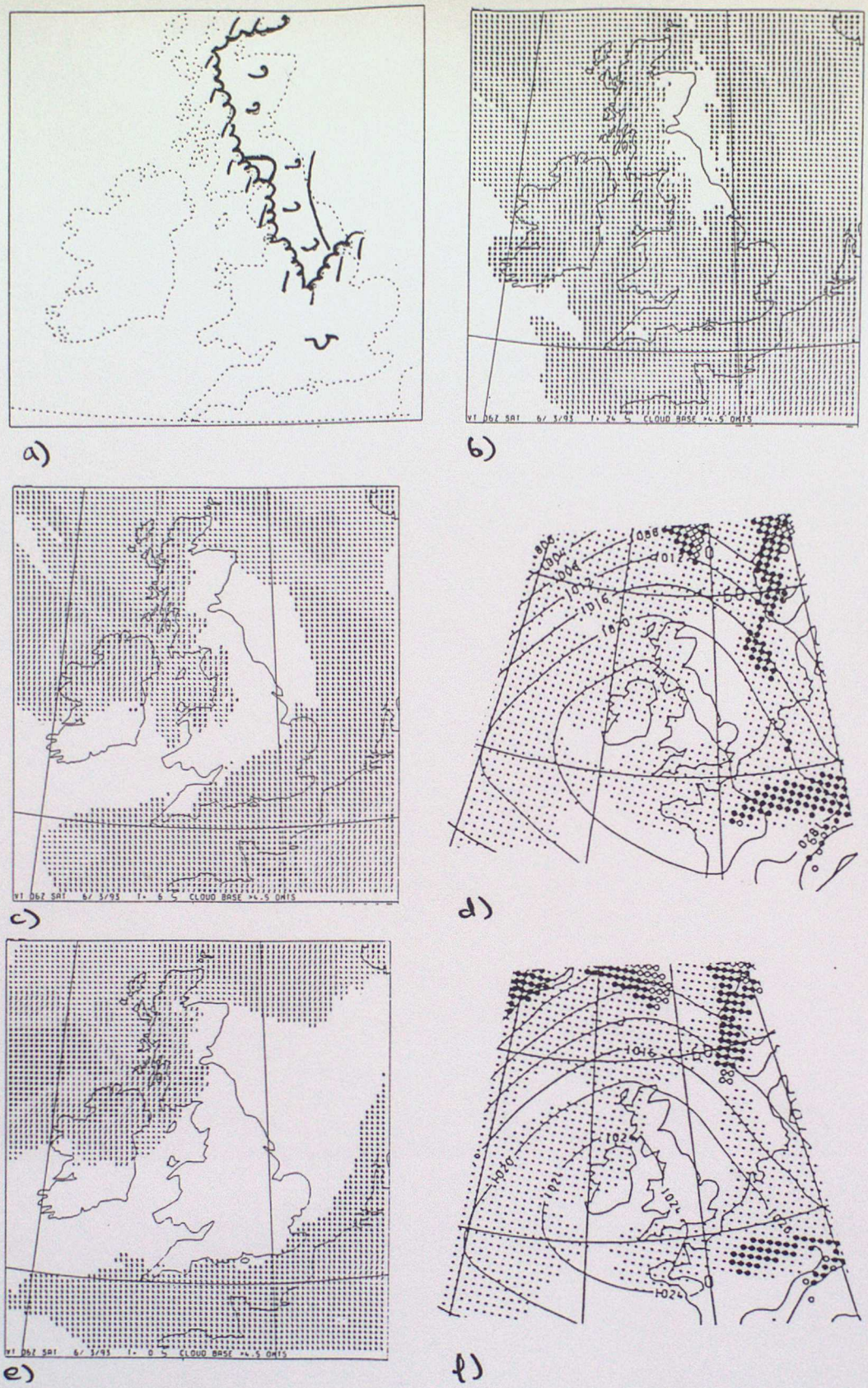


FIGURE 12. Comparison of observed and forecast low cloud cover at 6Z 6/3/93.
a) Observed cloud . Edge of low cloud, cirrus and clear areas marked.
b) T+24 operational mesoscale forecast from 6Z 5/3/93. Map shows area of low cloud >4.5 oktas. Figures are code for base height and clear areas are essentially cloud free.
c) as b) but T+6 operational mesoscale forecast from 0Z 6/3/93.
d) T+6 operational LAM forecast from 0Z 6/3/93. Map shows mean sea level pressure, low cloud cover greater than 4 oktas as dots, medium cloud as open circles and low plus medium cloud as filled circles.
e) as b) but T+0 operational mesoscale analysis for 6Z 6/3/93.
f) as d) but T+0 operational LAM analysis for 6Z 6/3/93.

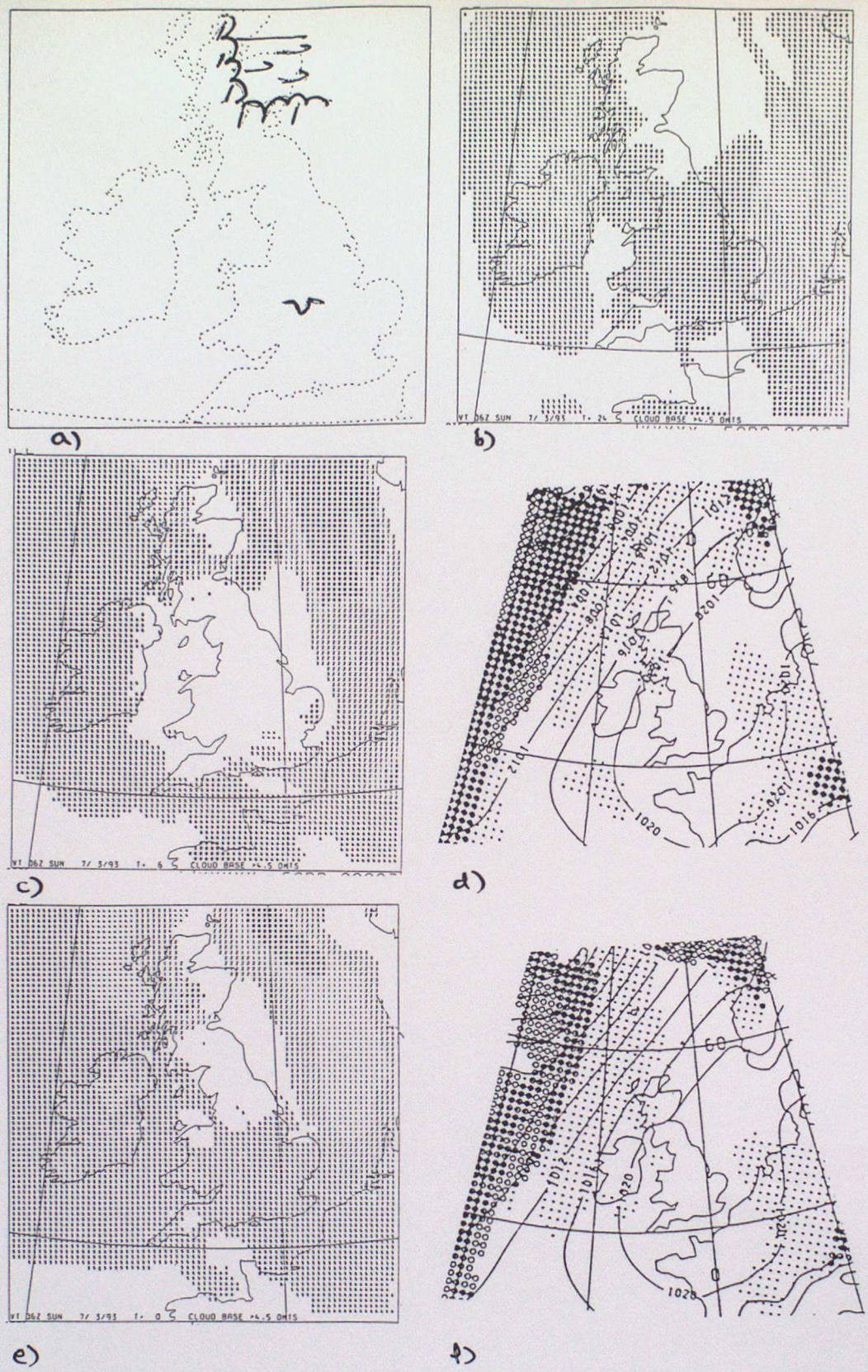


FIGURE 13. Comparison of observed and forecast low cloud cover at 6Z 7/3/93.
a) Observed cloud . Edge of low cloud, cirrus and clear areas marked.
b) T+24 operational mesoscale forecast from 6Z 6/3/93. Map shows area of low cloud >4.5 oktas. Figures are code for base height and clear areas are essentially cloud free.
c) as b) but T+6 operational mesoscale forecast from 0Z 7/3/93.
d) T+6 operational LAM forecast from 0Z 7/3/93. Map shows mean sea level pressure, low cloud cover greater than 4 oktas as dots, medium cloud as open circles and low plus medium cloud as filled circles.
e) as b) but T+0 operational mesoscale analysis for 6Z 7/3/93.
f) as d) but T+0 operational LAM analysis for 6Z 7/3/93.

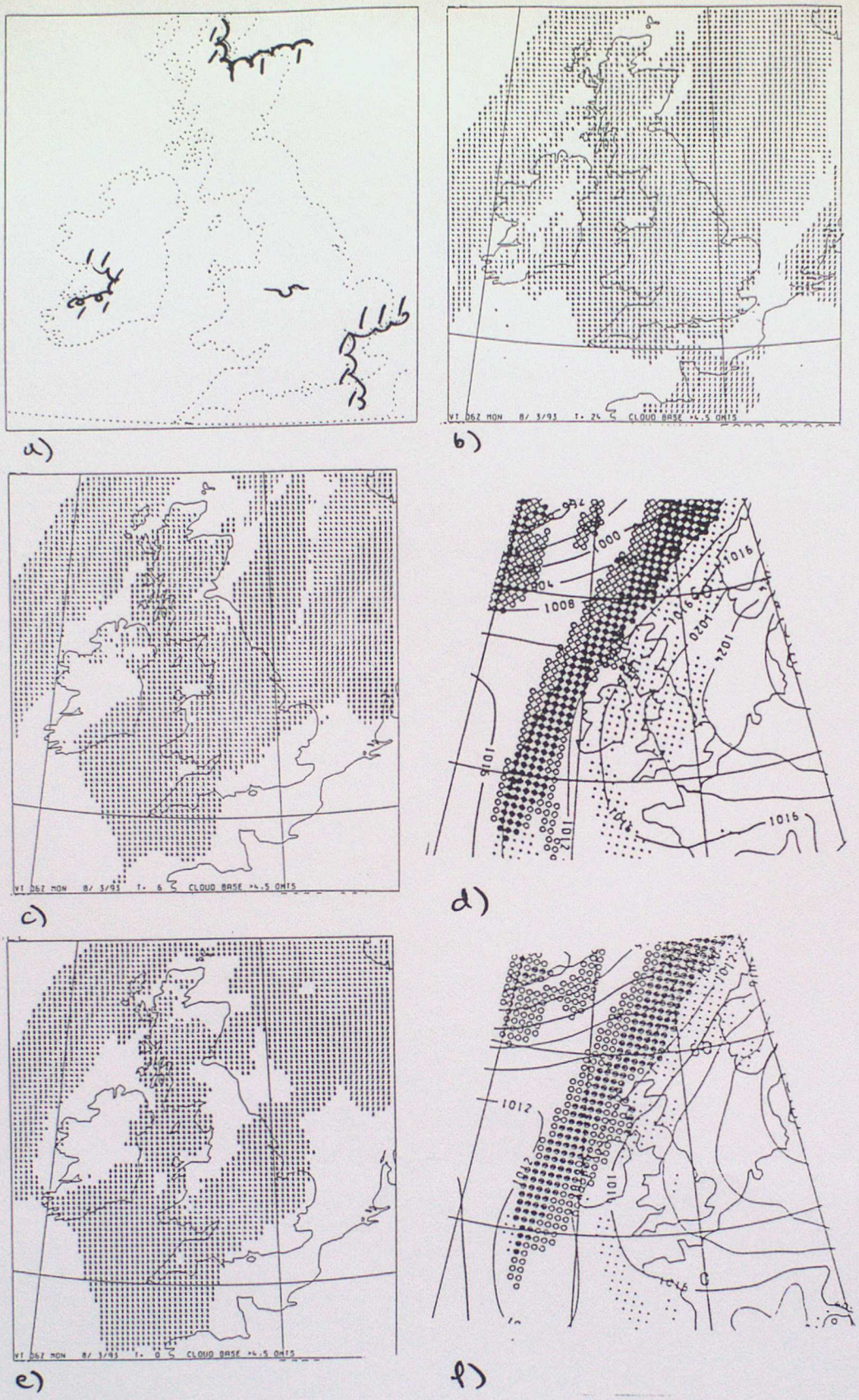


FIGURE 14. Comparison of observed and forecast low cloud cover at 6Z 8/3/93.
a) Observed cloud . Edge of low cloud, cirrus and clear areas marked.
b) T+24 operational mesoscale forecast from 6Z 7/3/93. Map shows area of low cloud >4.5 oktas. Figures are code for base height and clear areas are essentially cloud free.
c) as b) but T+6 operational mesoscale forecast from 0Z 8/3/93.
d) T+6 operational LAM forecast from 0Z 8/3/93. Map shows mean sea level pressure, low cloud cover greater than 4 oktas as dots, medium cloud as open circles and low plus medium cloud as filled circles.
e) as b) but T+0 operational mesoscale analysis for 6Z 8/3/93.
f) as d) but T+0 operational LAM analysis for 6Z 8/3/93.

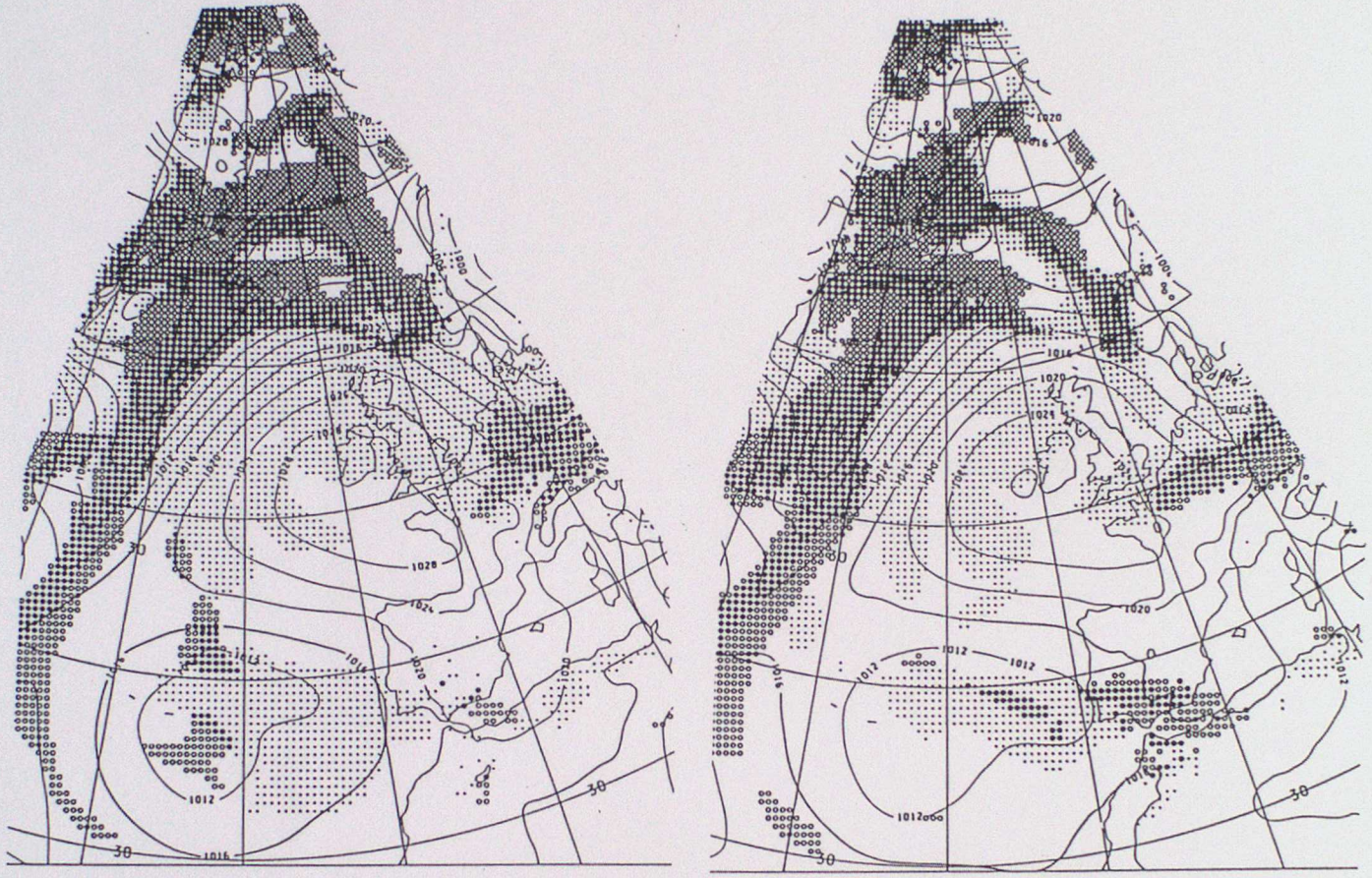


FIGURE 15. Comparison of LAM forecast and analysed low and medium cloud cover at 0Z 6/3/93.

a) T+24 operational LAM forecast from 0Z 5/3/93. Map shows mean sea level pressure, low cloud cover greater than 4 oktas as dots, medium cloud as open circles and low plus medium cloud as filled circles.

b) as a) but T+0 operational LAM analysis for 0Z 6/3/93.

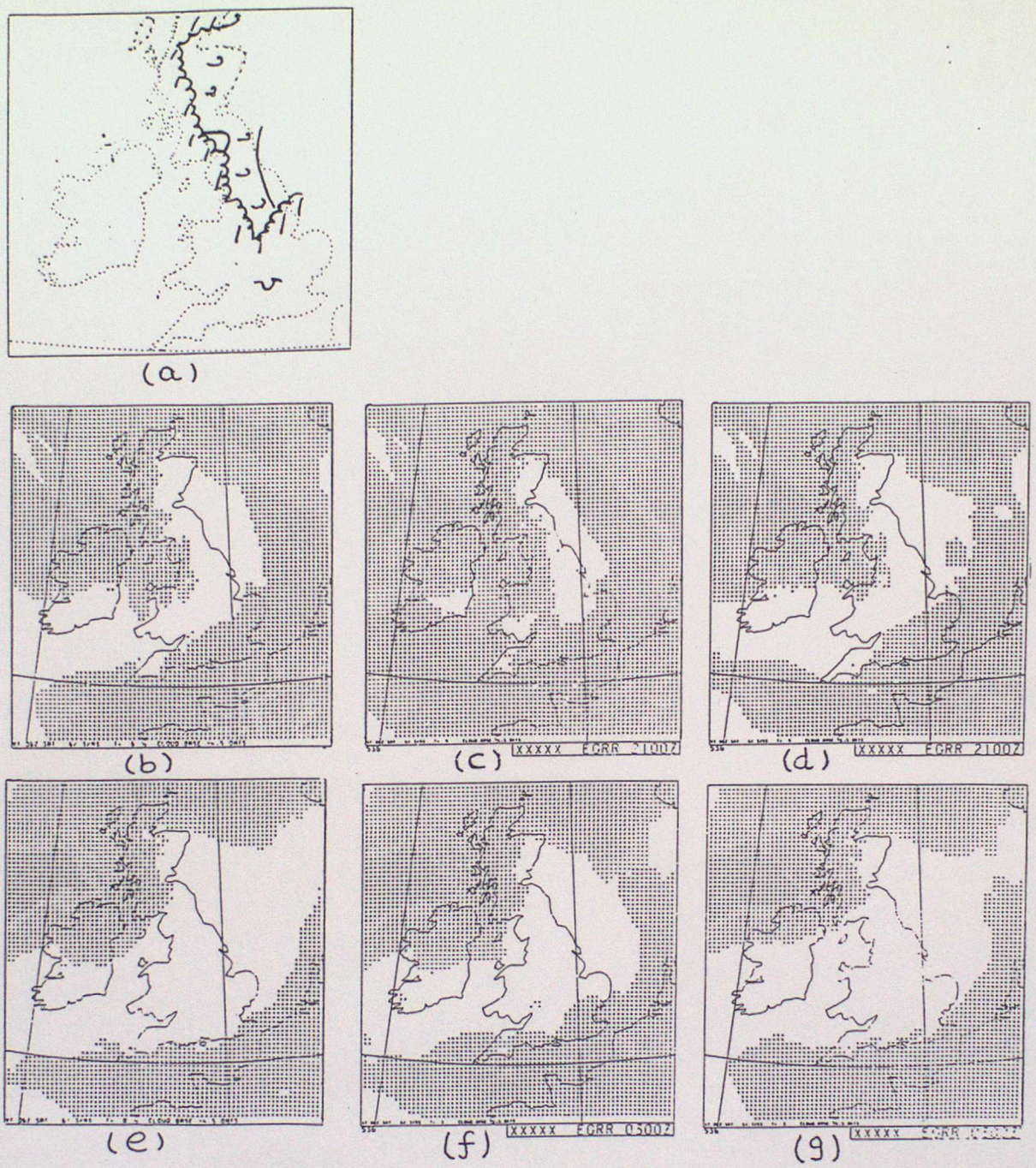


FIGURE 16. Comparison of observed, analysed and forecast low cloud cover at 6Z 6/3/93.

a) Observed cloud . Edge of low cloud areas marked.

b) T+6 operational mesoscale forecast from 0Z 6/3/93. Map shows area of low cloud >4.5 oktas (clear areas are essentially cloud free).

c) as b) but rerun without radiosonde humidity data.

d) as b) but rerun without MOPS data.

e) as c) but T+0 operational mesoscale analysis for 6Z 6/3/93.

f) as e) but rerun without radiosonde humidity data.

g) as e) but rerun without MOPS data.

FIGURE 17. Comparison of observed, analysed and forecast low cloud cover at 6Z 7/3/93.

a) Observed cloud . Edge of low cloud areas marked.

b) T+6 operational mesoscale forecast from 0Z 7/3/93. Map shows area of low cloud >4.5 oktas (clear areas are essentially cloud free).

c) as b) but rerun without radiosonde humidity data.

d) as b) but rerun without MOPS data.

e) as c) but T+0 operational mesoscale analysis for 6Z 7/3/93.

f) as e) but rerun without radiosonde humidity data.

g) as e) but rerun without MOPS data.

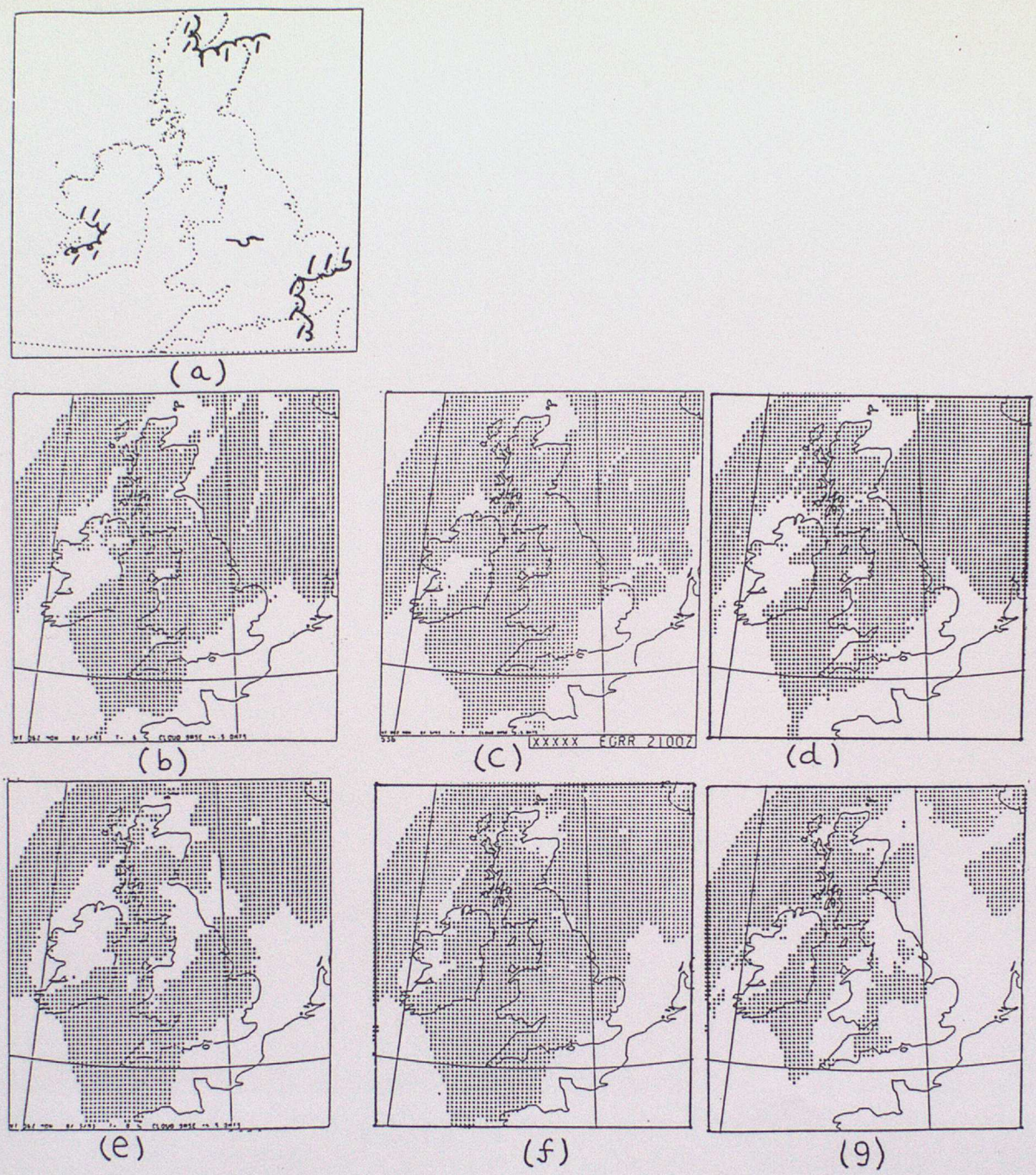


FIGURE 18. Comparison of observed, analysed and forecast low cloud cover at 6Z 8/3/93.

a) Observed cloud . Edge of low cloud areas marked.

b) T+6 operational mesoscale forecast from 0Z 8/3/93. Map shows area of low cloud >4.5 oktas (clear areas are essentially cloud free).

c) as b) but rerun without radiosonde humidity data.

d) as b) but rerun without MOPS data.

e) as c) but T+0 operational mesoscale analysis for 6Z 8/3/93.

f) as e) but rerun without radiosonde humidity data.

g) as e) but rerun without MOPS data.

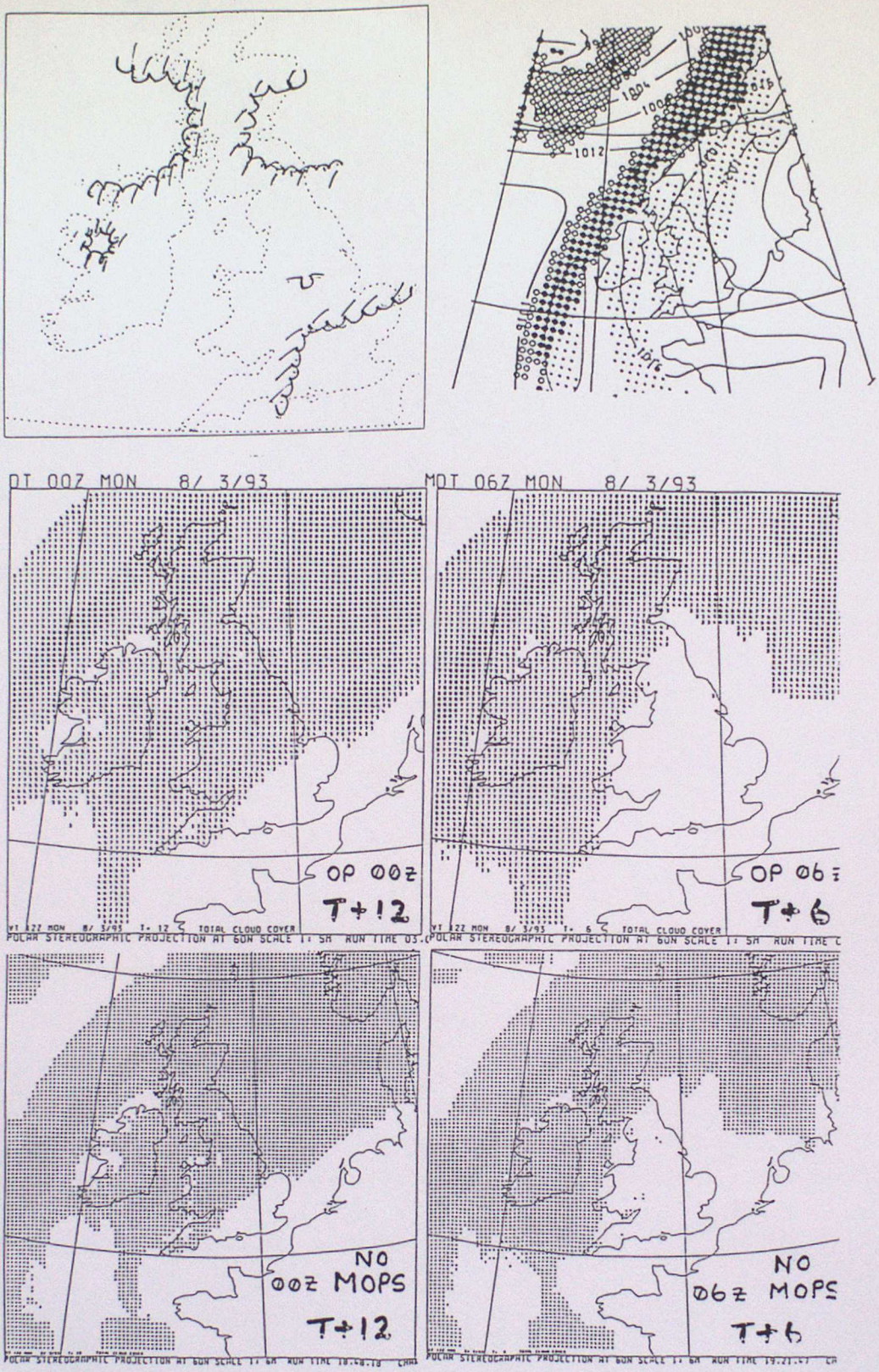


FIGURE 19. Comparison of observed and forecast low cloud cover at 12Z 8/3/93.
a) Observed cloud . Edge of low cloud areas marked.
b) T+12 operational LAM forecast from 0Z 8/3/93. Map shows mean sea level pressure, low cloud cover greater than 4 oktas as dots, medium cloud as open circles and low plus medium cloud as filled circles.
c) T+12 operational mesoscale forecast from 0Z 8/3/93. Map shows area of total cloud >3 oktas.
d) as c) but T+6 operational mesoscale forecast from 6Z 8/3/93.
e) as c) but rerun without MOPS data from 0Z 8/3/93.
f) as d) but rerun without MOPS data from 6Z 8/3/93.

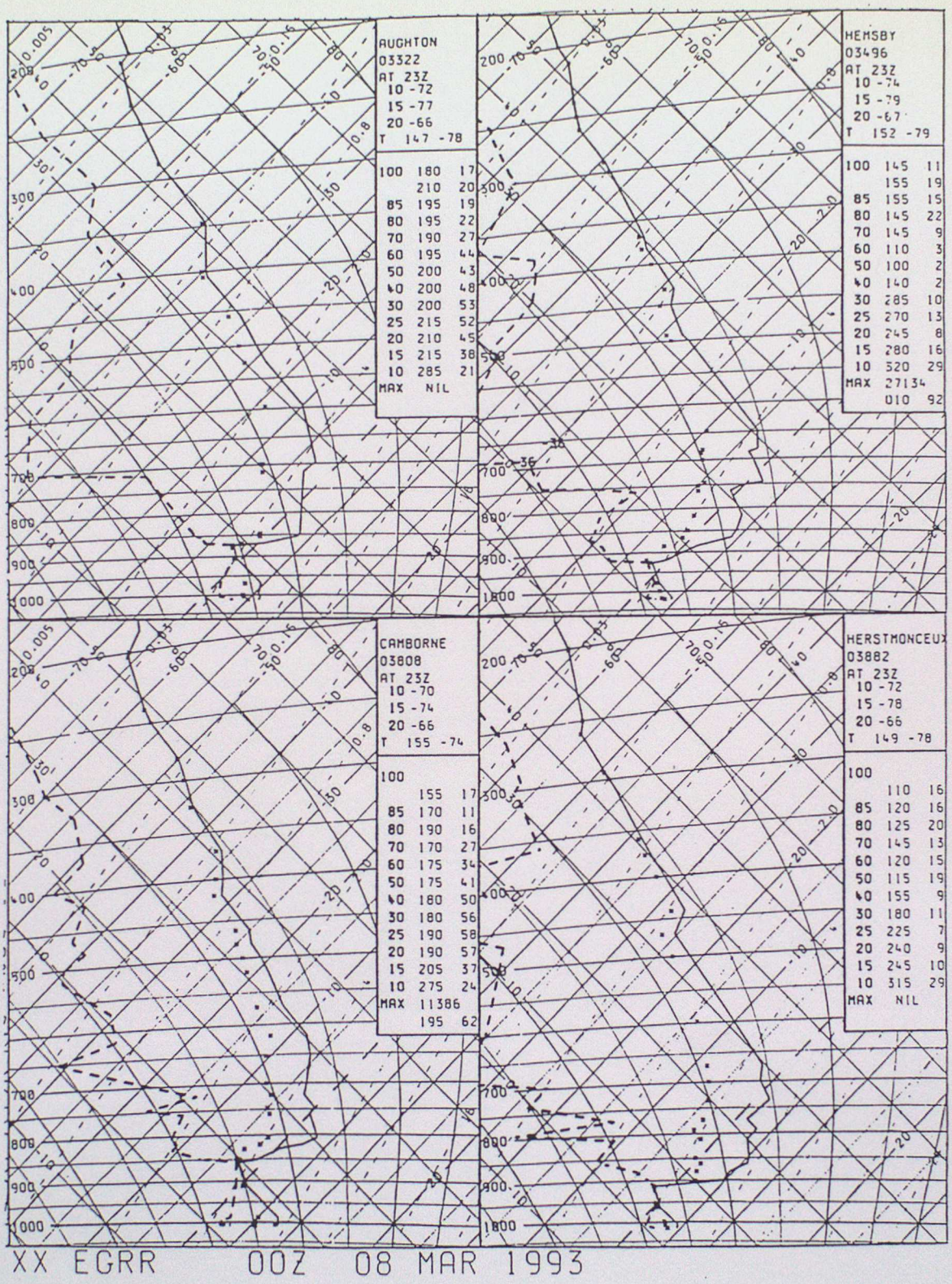


FIGURE 20. Observed radiosonde ascents for selected stations in England at 0Z 8/3/93.

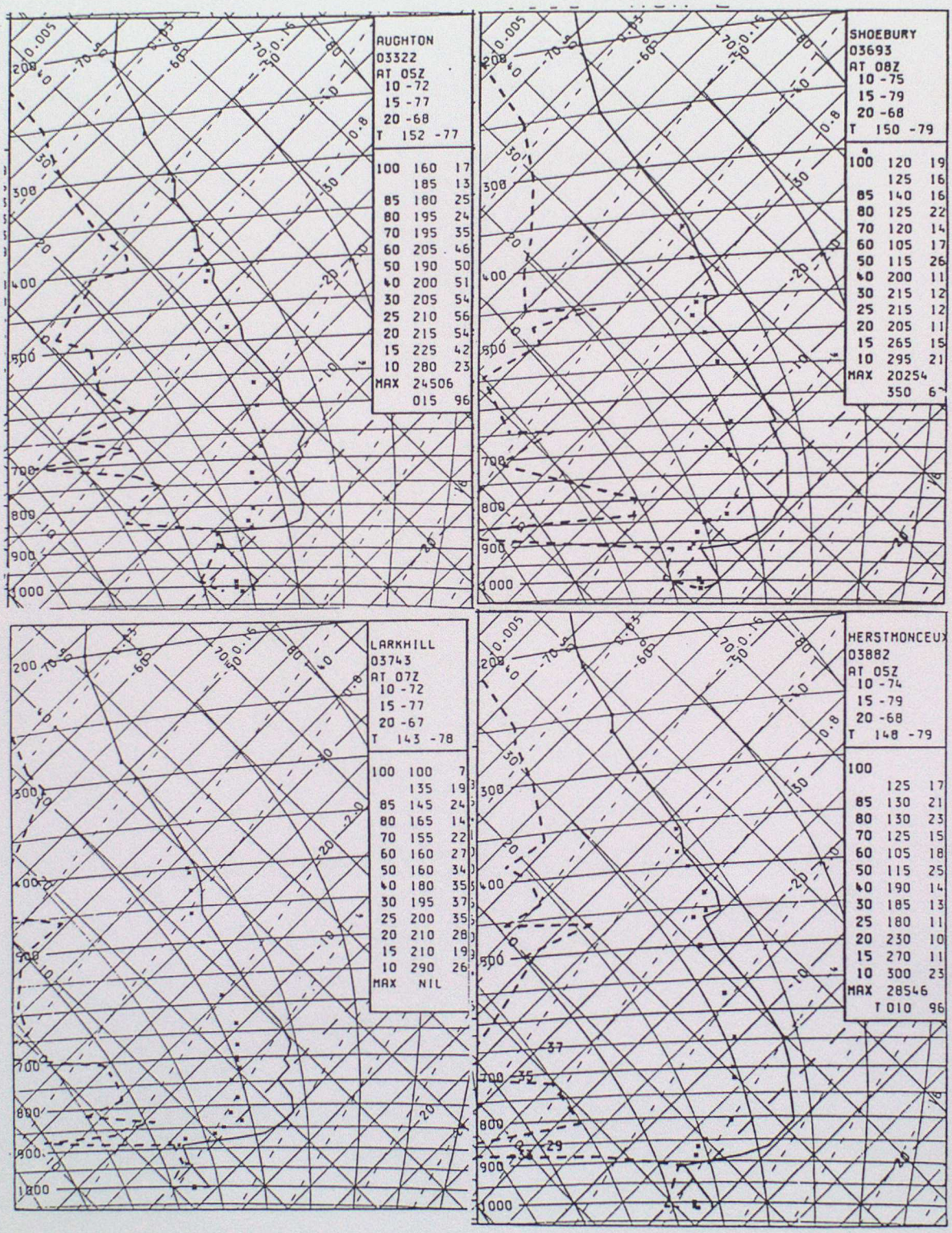


FIGURE 21. Observed radiosonde ascents for selected stations in England at 6Z 8/3/93.

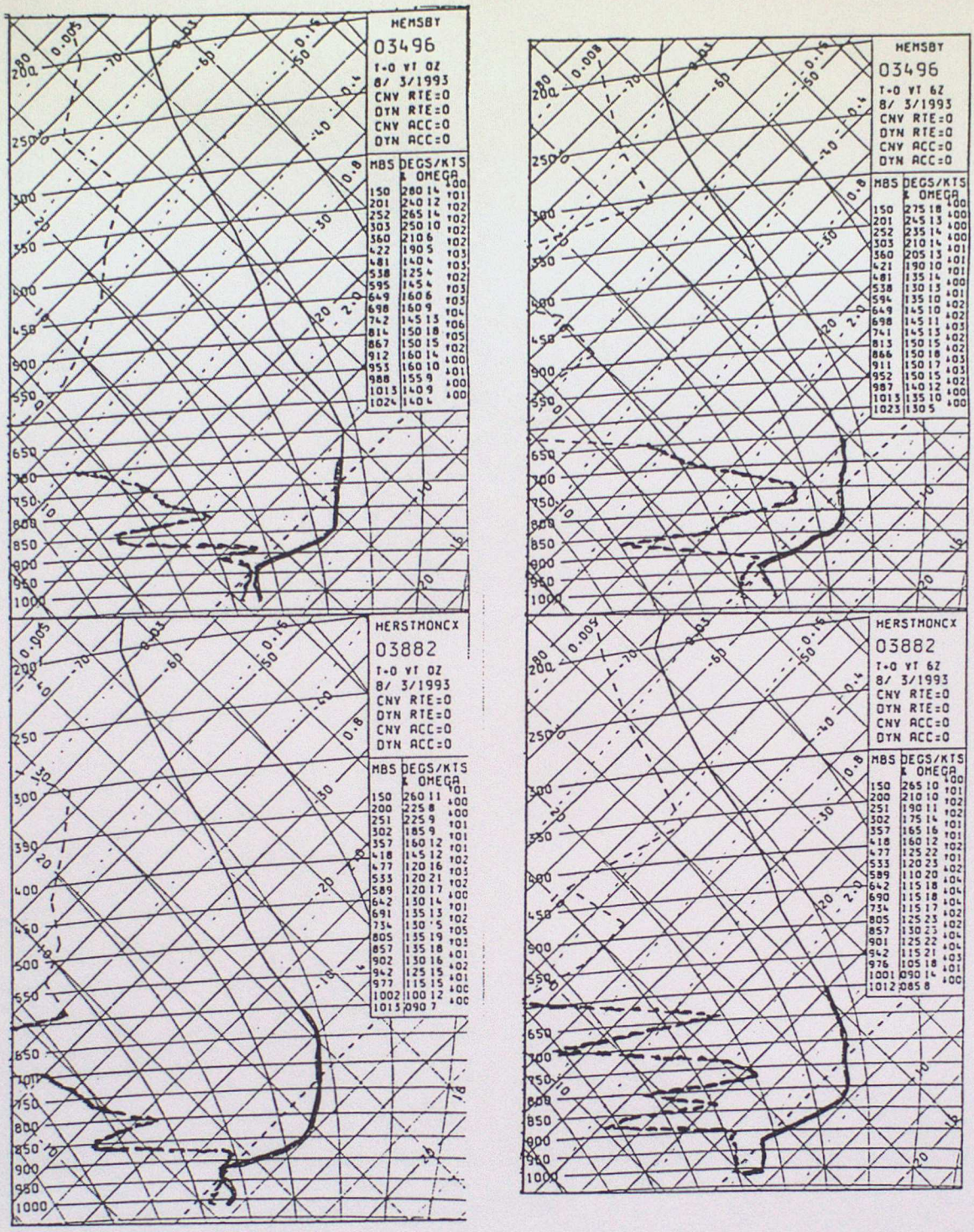


FIGURE 22. Ascents taken from operational mesoscale analyses for 0Z 8/3/93 and 6Z 8/3/93.

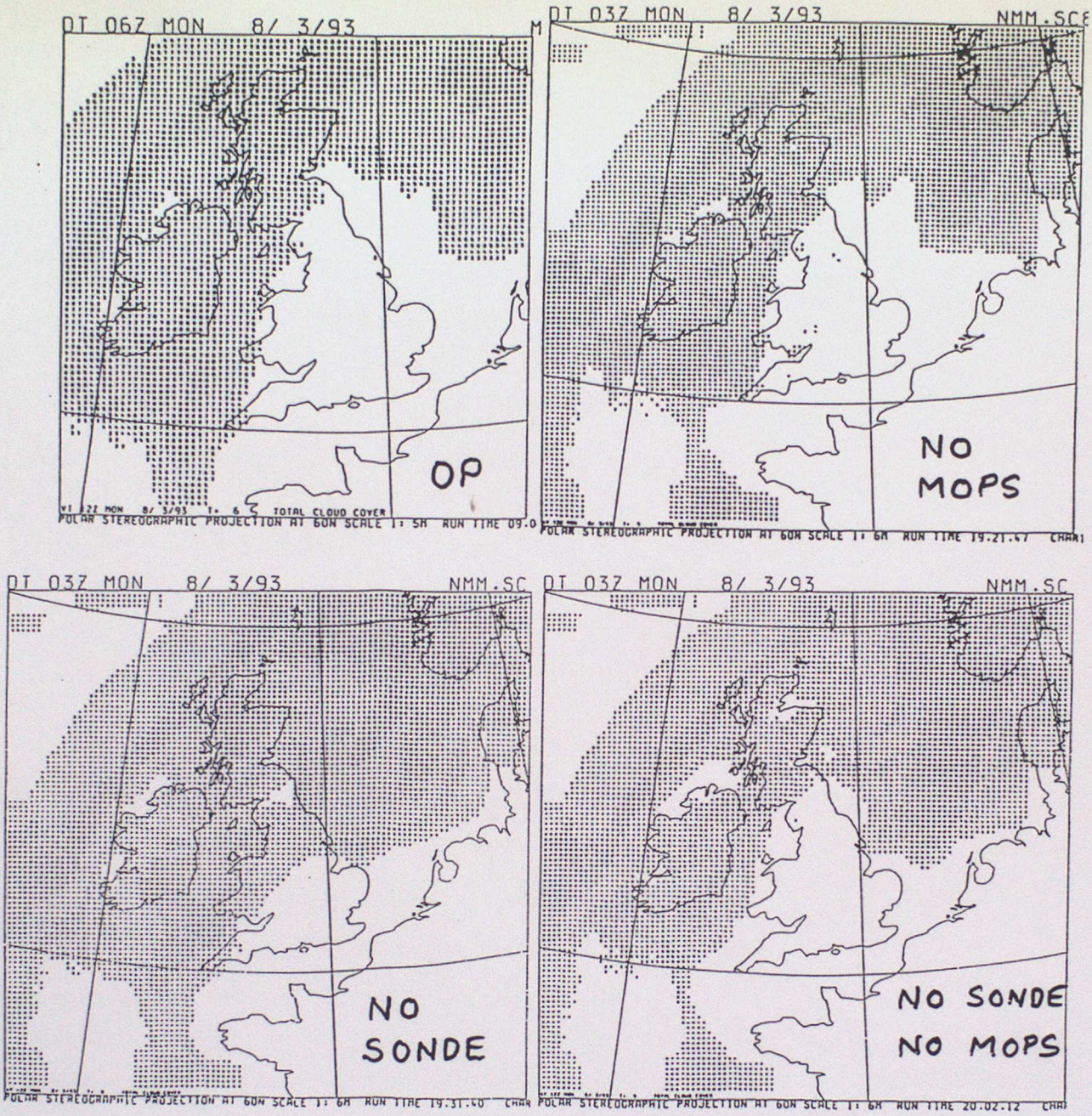


FIGURE 23. Comparison of forecast total cloud cover for 12Z 8/3/93.
a) T+6 operational mesoscale forecast.
b) T+6 mesoscale forecast run without MOPS data.
c) T+6 mesoscale forecast run without radiosonde humidity data.
d) T+6 mesoscale forecast run without MOPS or radiosonde humidity data.

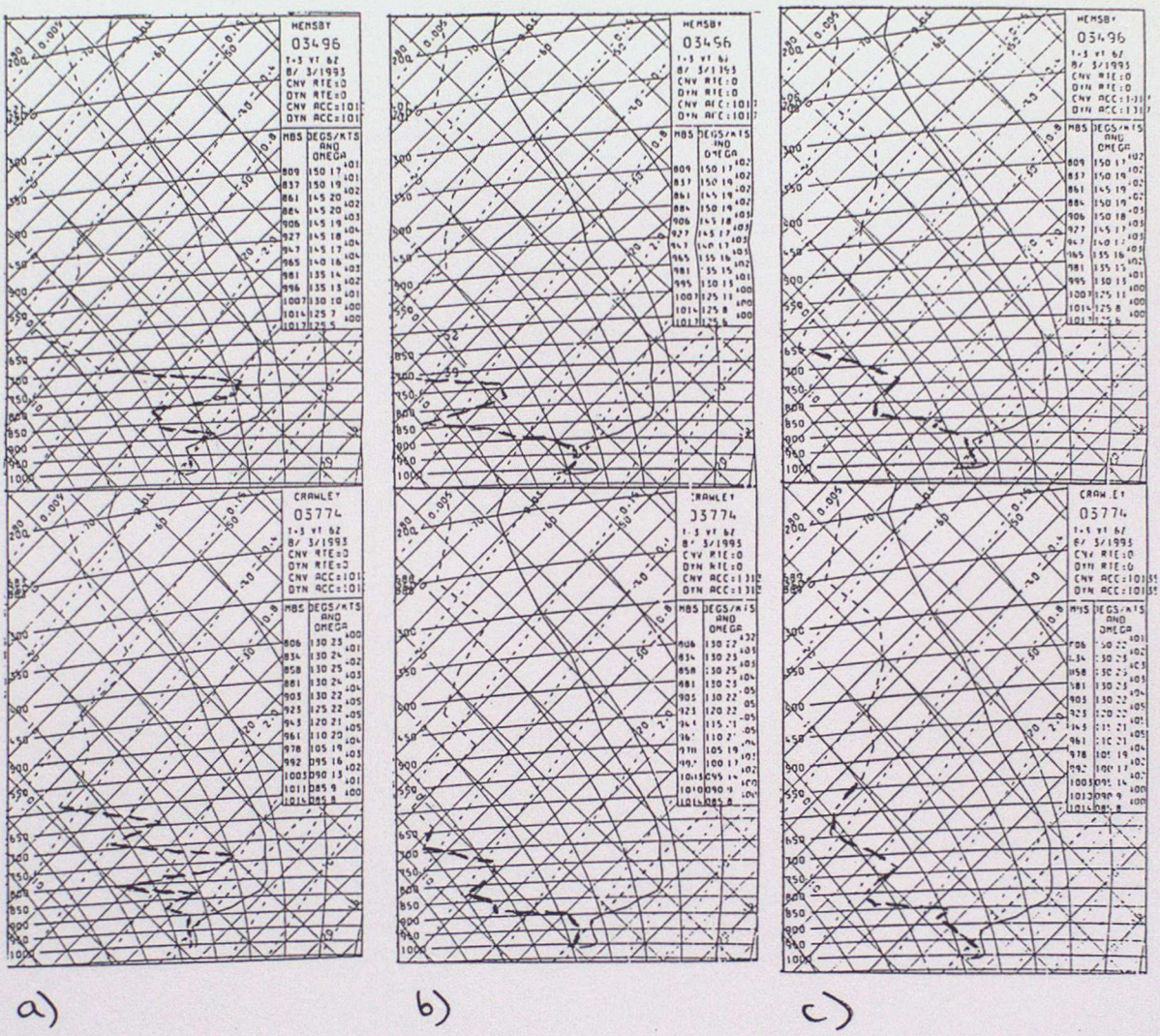


FIGURE 24. Comparison of ascents taken from mesoscale analyses for 6Z 8/3/93.
a) assimilation run without radiosonde humidity data.
b) assimilation run without MOPS data.
c) assimilation run without MOPS and radiosonde humidity data.

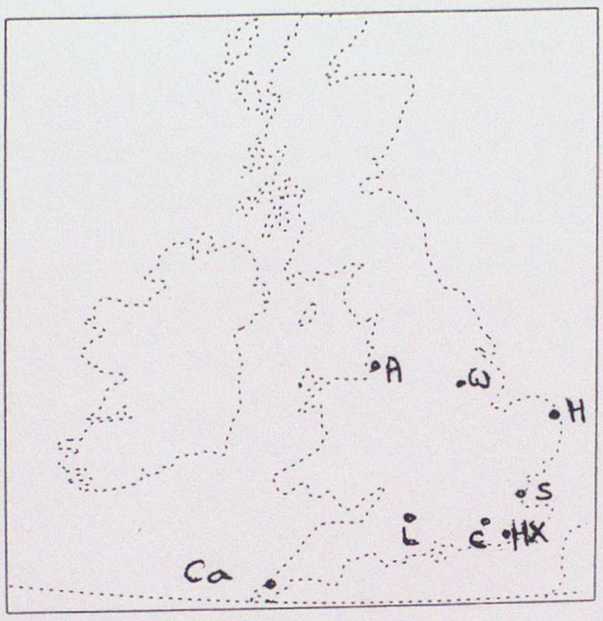


FIGURE 25. Location of the UK radiosonde stations referred to in the text and other figures.
Ca = Camborne, L = Larkhill, C = Crawley
HX = Herstmonceux, S = Shoeburyness
H = Hemsby, W = Waddington, A = Aughton.

FIGURE 26. Comparison of observed and analysed total cloud cover at 6Z 8/3/93.
a) Observed cloud . Edge of low cloud areas marked.
b) T+0 mesoscale analysis valid at 6Z 8/3/93 using climate/LAM convection parameters. Map shows area of total cloud >3 oktas shaded with contour intervals at 3,5,7 and 9 oktas.
c) as b) but T+0 mesoscale analysis using operational physics and no MOPS data. d) as c) but T+0 mesoscale analysis using climate/LAM convection parameters and no MOPS data
e) as c) but T+0 mesoscale analysis using climate critical relative humidity and no MOPS data
f) as e) but with climate convection parameters, climate critical relative humidity and no MOPS data

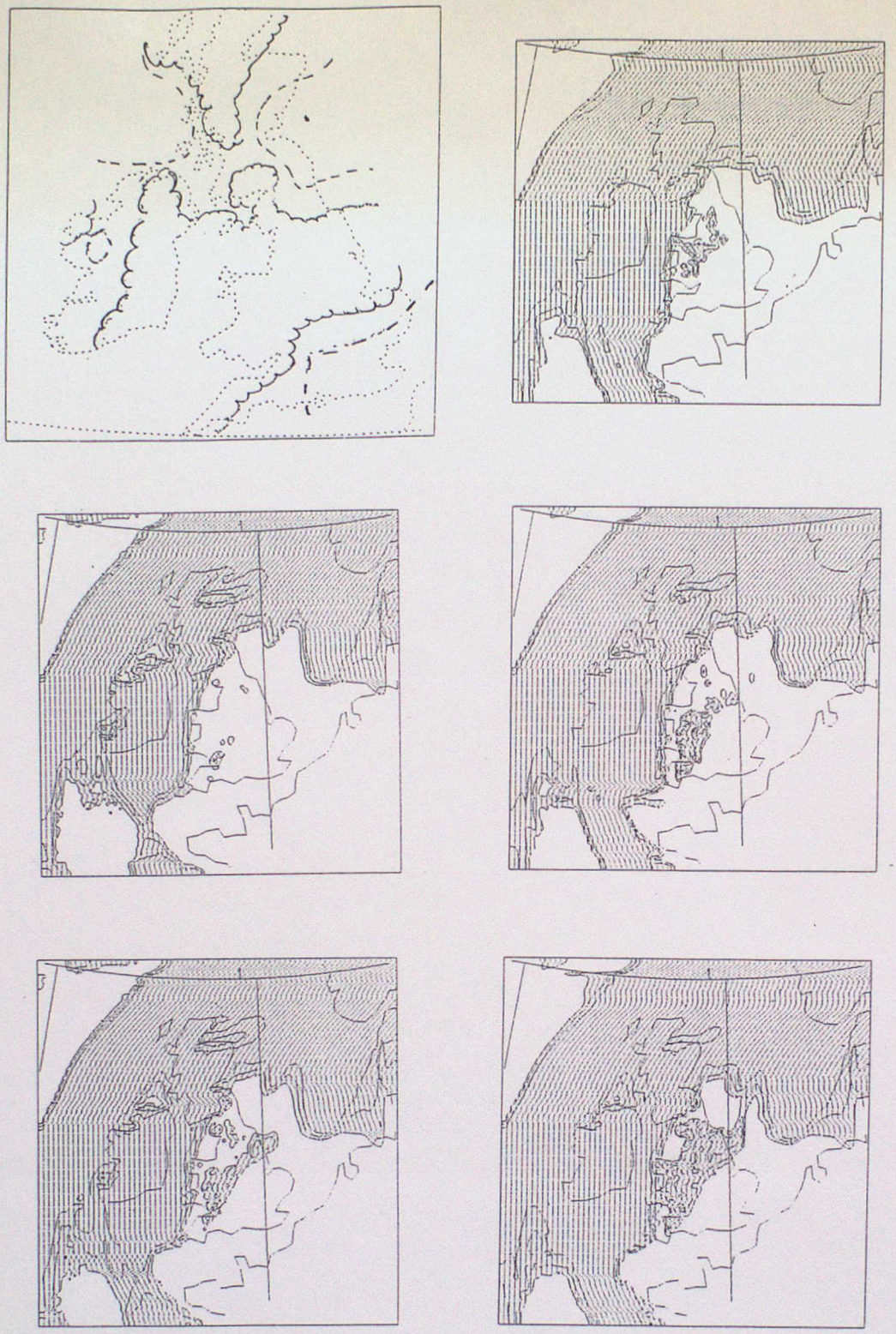


FIGURE 27. Comparison of observed and forecast total cloud cover at 12Z 8/3/93.
a) Observed cloud . Edge of low cloud areas marked.
b) T+6 mesoscale forecast valid at 12Z 8/3/93 using climate/LAM convection parameters. Map shows area of total cloud >3 oktas shaded with contour intervals at 3,5,7 and 9 oktas.
c) as b) but T+6 mesoscale forecast using operational physics and no MOPS data. d) as c) but T+6 mesoscale forecast using climate/LAM convection parameters and no MOPS data
e) as c) but T+6 mesoscale forecast using climate critical relative humidity and no MOPS data
f) as e) but with climate convection parameters, climate critical relative humidity and no MOPS data

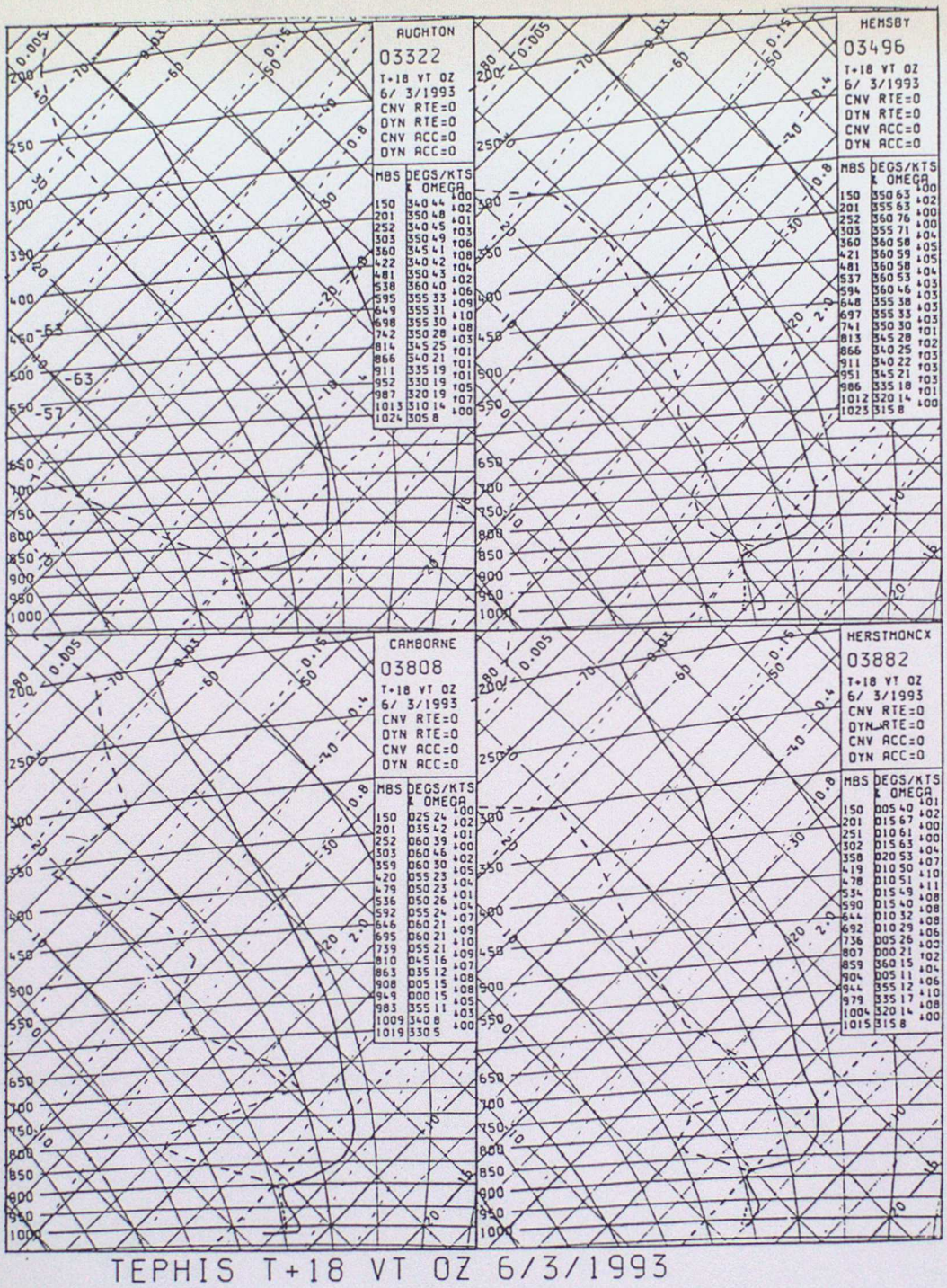


FIGURE 28. Ascents taken from T+18 operational mesoscale forecast from 6Z 5/3/93 valid at 0Z 6/3/93.

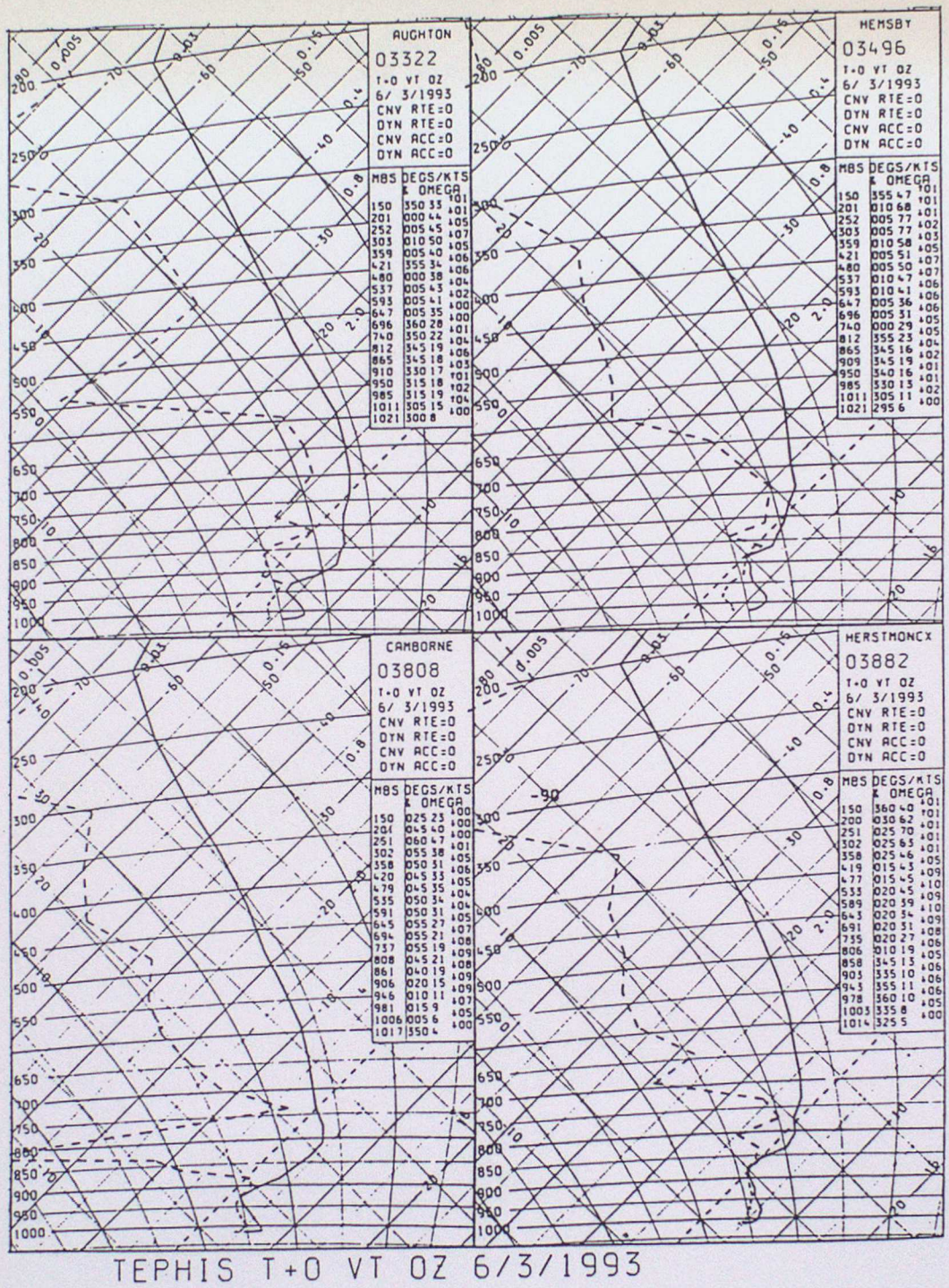


FIGURE 29. Ascents taken from operational mesoscale analysis for 0Z 6/3/93.

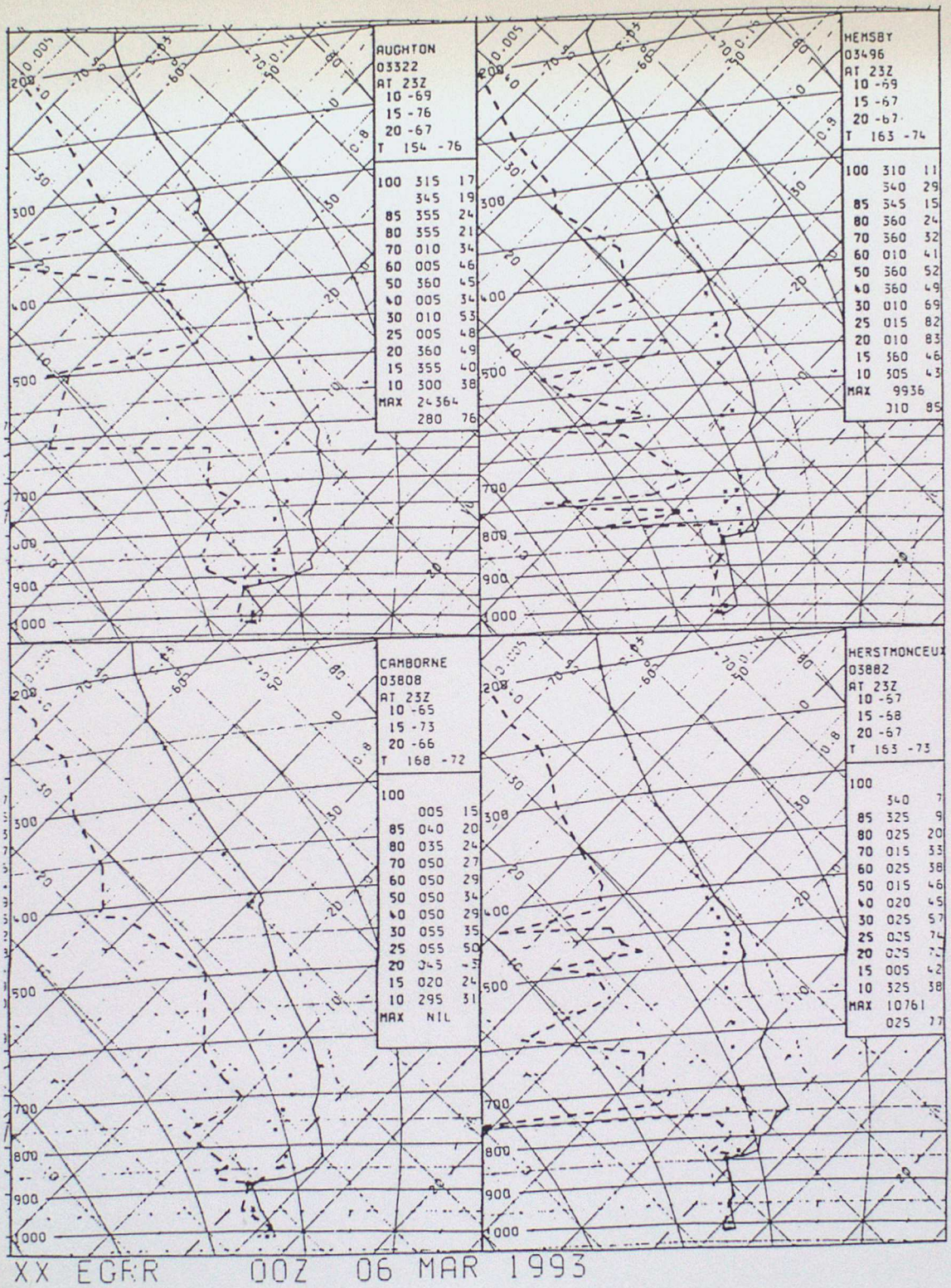


FIGURE 30. Observed radiosonde ascents for selected stations in England at 0Z 6/3/93.

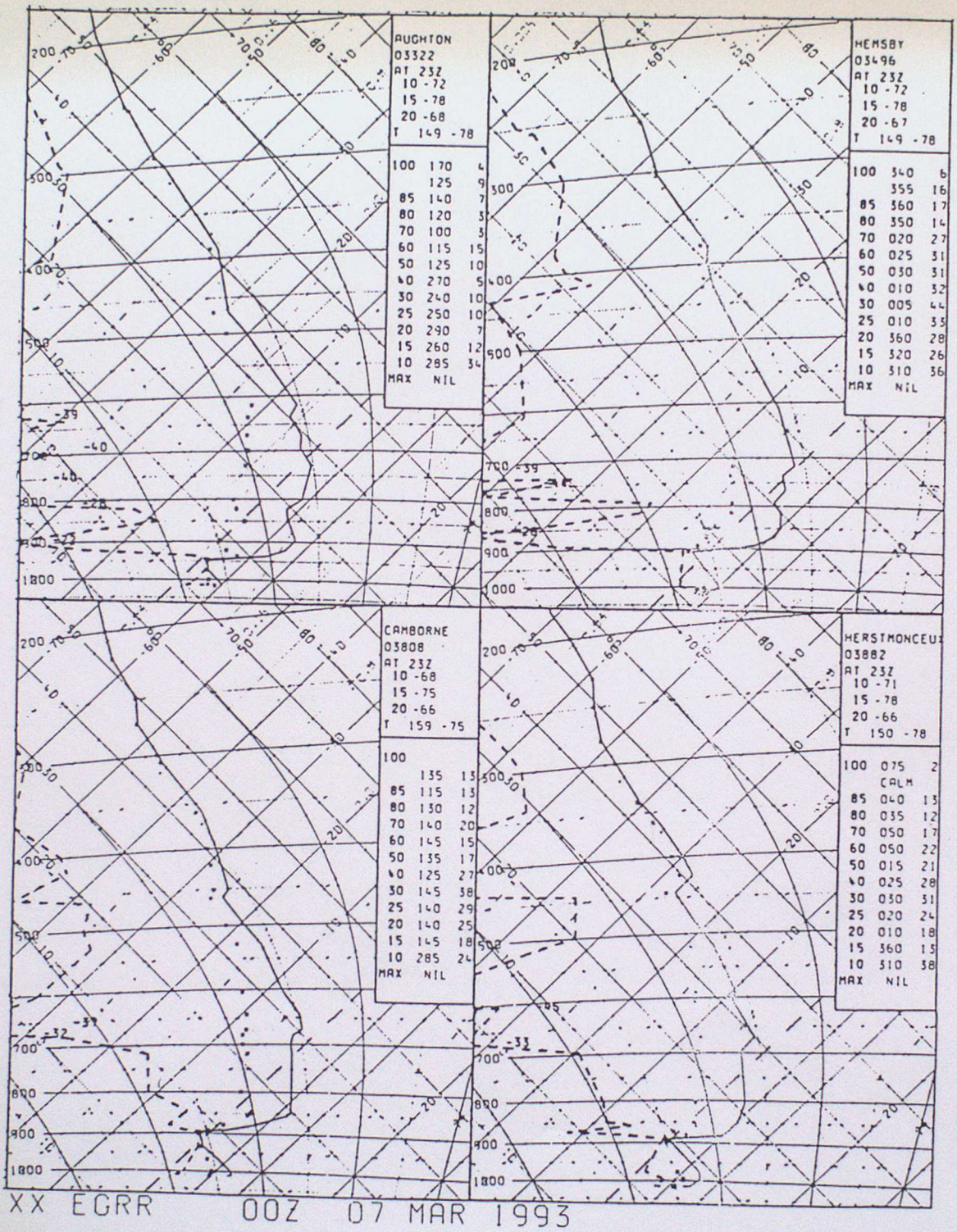


FIGURE 31. Observed radiosonde ascents for selected stations in England at 0Z 7/3/93.